CHAPTER 4: OFFSITE CONSEQUENCE ANALYSIS

You are required to conduct an offsite consequence analysis to provide information to the government and the public about the potential consequences of an accidental chemical release at your facility. The offsite consequence analysis (OCA) consists of two elements:

g   A worst-case release scenario and
g   Alternative release scenarios.

To simplify the analysis and ensure a common basis for comparisons, EPA has defined the worst-case scenario as the release of the largest quantity of a regulated substance from a single vessel or process line failure that results in the greatest distance to an endpoint. In broad terms, the distance to the endpoint is the distance a toxic vapor cloud, heat from a fire, or blast waves from an explosion will travel before dissipating to the point that serious injuries from short-term exposures will no longer occur.

This chapter gives guidance on how to perform the OCA for the six regulated substances that are used or produced at WWTPs:

g   Chlorine (toxic)
g   Sulfur dioxide (toxic)
g   Anhydrous ammonia (toxic)
g   Aqueous ammonia (20 percent or greater, toxic)
g   Methane (digester gas, flammable)

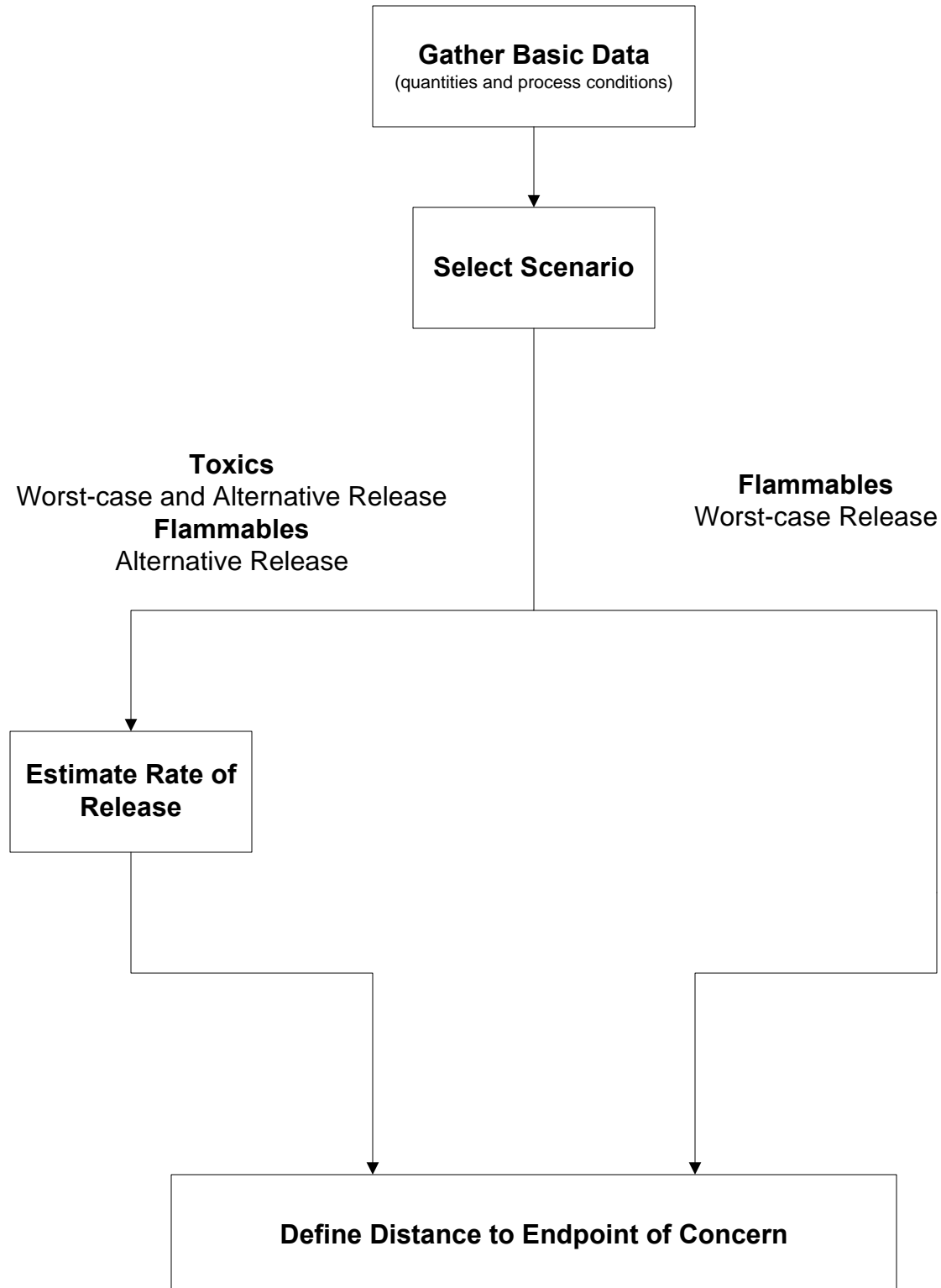Exhibit 4-1 shows the basic steps used to conduct the OCA.

RMP*Comp™

To assist those using this guidance, the National Oceanic and Atmospheric Administration (NOAA) and EPA have developed a software program, RMP*Comp™, that performs the calculations described in this document. This software can be downloaded from the EPA website at http://www.epa.gov/swercepp/tools/rmp-comp/rmp-comp.html.

The methodology and reference tables of distances presented here are optional. You are not required to use this guidance. You may use publicly available or proprietary air dispersion models to do your offsite consequence analysis, subject to certain conditions. If you choose to use other models, you should review the rule and Chapter 4 of the *General Guidance for Risk Management Programs*, which outline required conditions for use of other models.

EXHIBIT 4-1
STEPS FOR OFFSITE CONSEQUENCE ANALYSIS

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                        ┌─────────────────────────────┐
                        │    Gather Basic Data         │
                        │ (quantities and process      │
                        │        conditions)           │
                        └─────────────────────────────┘
                                     │
                                     ▼
                        ┌─────────────────────────────┐
                        │      Select Scenario         │
                        └─────────────────────────────┘
                                     │
```

Toxics
Worst-case and Alternative Release
Flammables
Alternative Release

Flammables
Worst-case Release

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    ┌──────────────────┐
    │ Estimate Rate of │
    │     Release      │
    └──────────────────┘
              │
              ▼
    ┌────────────────────────────────────────────────────┐
    │      Define Distance to Endpoint of Concern         │
    └────────────────────────────────────────────────────┘
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Some of the results obtained using the methods in this document may be conservative (i.e., they may overestimate the distance to endpoints). Complex models that can account for many site-specific factors may give less conservative estimates of offsite consequences than the simple methods used in this guidance. This is particularly true for alternative scenarios, for which EPA has not specified many assumptions. However, complex models may be expensive and require considerable expertise to use; this guidance is designed to be simple and straightforward. You will need to consider these tradeoffs in deciding how to carry out your required consequence analyses.

This chapter presents discussions and tables for the worst-case scenario for all six substances listed above (section 4.1), followed by discussions and tables for alternative scenarios for the six substances (section 4.2). Because many WWTPs store chlorine and sulfur dioxide in buildings, section 4.3 discusses methods for estimating the mitigating effects of buildings. The remaining sections provide guidance on defining offsite impacts (section 4.4), documentation (section 4.5), and the symbols used in the chapter (section 4.6).

The guidance presented in this chapter is intended for users — that is, it does not contain any explanations of how the guidance was derived. Those readers who are interested in obtaining an explanation can obtain from EPA a document entitled *Backup Information for the Hazard Assessments in the RMP Offsite Consequence Analysis Guidance, the Guidance for Wastewater Treatment Facilities and the Guidance for Ammonia Refrigeration—Anhydrous Ammonia, Aqueous Ammonia, Chlorine and Sulfur Dioxide*.

4.1   WORST-CASE RELEASE SCENARIOS

This section provides guidance on how to analyze worst-case scenarios. Information is provided on the general requirements of the regulations, followed by specific sections on chlorine, sulfur dioxide, anhydrous ammonia, aqueous ammonia, and methane. Exhibit 4-2 presents the parameters that must be used in worst-case and alternative release scenarios.

GENERAL REQUIREMENTS FOR TOXIC SUBSTANCES

The following information is required for worst-case release analysis of toxic substances:

The *worst-case release quantity* Q (lb) is the greater of the following:

g   For substances in vessels, the greatest amount held in a single vessel, taking into account administrative controls that limit the maximum quantity; or

g   For substances in pipes, the greatest amount in a pipe, taking into account administrative controls that limit the maximum quantity.

For vessels, you need only consider the largest amount in the vessel, regardless of interconnections with pipes and other vessels. Similarly, if the largest quantity is contained in a pipe, you need not add the quantity in vessels at the end of the

pipelines. You may be able to think of scenarios in which a quantity greater than Q as defined above can be released, but EPA does not require you to model such scenarios as worst-case (you may want to consider modeling them as alternative scenarios).

Weather conditions. The rule allows anyone who conducts his or her OCA based on this guidance to use specific default weather conditions for wind speed, stability class, average temperature, and humidity. Liquids other than gases liquefied by refrigeration should be considered to be released at the highest daily maximum temperature, based on local data for the previous three years, or at process temperature, whichever is the higher. You can obtain weather data from local weather stations. You can also obtain temperature and wind speed data from the National Climatic Data Center at (828) 271-4800.

For the worst-case scenario, the release must be assumed to take place at *ground level*.

The *toxic endpoint*s are:

Ammonia	0.14 mg/L (200 ppm)
Chlorine	0.0087 mg/L (3 ppm)
Sulfur Dioxide	0.0078 mg/L (3 ppm)

These airborne concentrations are the maximum airborne concentrations below which it is believed that nearly all individuals can be exposed for up to one hour without experiencing or developing irreversible or other serious health effects or symptoms which could impair an individual's ability to take protective action.

The regulations require you to take account of whether your site is rural or urban. The regulations state that "urban means that there are many obstacles in the immediate area; obstacles include buildings or trees. Rural means that there are no buildings in the immediate area and the terrain is generally flat or unobstructed." Some areas outside of cities may still be considered urban if they are forested.

The regulations require you to use tables or models for atmospheric dispersion analysis that appropriately account for gas density. For the specific case of WWTPs, chlorine and sulfur dioxide are always dense gases (that is, denser than air). Anhydrous ammonia, if released from the liquid space of a container in which it is liquefied under pressure, forms a denser-than-air vapor cloud. Ammonia evaporating from a pool of aqueous ammonia is treated as neutrally buoyant (that is, it has about the same density as air).

You are only allowed to take account of passive mitigation systems, not active ones. Passive mitigation systems could include:

g   Diked areas that confine a liquid pool and reduce the surface area available for evaporation

EXHIBIT 4-2
REQUIRED PARAMETERS FOR MODELING (40 CFR 68.22)

WORST CASE	ALTERNATIVE SCENARIO
Endpoints (§68.22(a))	
Toxic endpoints are listed in part 68 Appendix A.	Toxic endpoints are listed in part 68 Appendix A.
For flammable substances, endpoint is overpressure of 1 pound per square inch (psi) for vapor cloud explosions.	gFor flammable substances, endpoint is overpressure of 1 psi for vapor cloud explosions gRadiant heat level of 5 kilowatts per square meter (kW/m^2) for 40 seconds for heat from fires (or equivalent dose) gLower flammability limit (LFL) as specified in NFPA documents or other generally recognized sources for vapor cloud fires.
Wind speed/stability (§68.22(b))	
This guidance assumes 1.5 meters per second and F stability. For other models, use wind speed of 1.5 meters per second and F stability class unless you can demonstrate that local meteorological data applicable to the site show a higher minimum wind speed or less stable atmosphere at all times during the previous three years. If you can so demonstrate, these minimums may be used for site-specific modeling.	This guidance assumes wind speed of 3 meters per second and D stability. For other models, you may use typical meteorological conditions for your site.
Ambient temperature/humidity (§68.22(c))	
This guidance assumes 25EC (77EF) and 50 percent humidity. For other models for toxic substances, you must use the highest daily maximum temperature and average humidity for the site during the past three years.	This guidance assumes 25EC and 50 percent humidity. For other models, you may use average temperature/humidity data gathered at the site or at a local meteorological station.
Height of release (§68.22(d))	
For toxic substances, you must assume a ground level release.	This guidance assumes a ground-level release. For other models, release height may be determined by the release scenario.
Surface roughness (§68.22(e))	
Use urban (obstructed terrain) or rural (flat terrain) topography, as appropriate.	Use urban (obstructed terrain) or rural (flat terrain) topography, as appropriate.
Dense or neutrally buoyant gases (§68.22(f))	
Tables or models used for dispersion of regulated toxic substances must appropriately account for gas density.	Tables or models used for dispersion must appropriately account for gas density.
Temperature of released substance (§68.22(g))	
You must consider liquids (other than gases liquefied by refrigeration) to be released at the highest daily maximum temperature, from data for the previous three years, or at process temperature, whichever is higher. Assume gases liquefied by refrigeration at atmospheric pressure to be released at their boiling points.	Substances may be considered to be released at a process or ambient temperature that is appropriate for the scenario.

g   Buildings, provided that the building can be shown to withstand the events
         that caused the release (see Section 4.3 for more information)

Active mitigation systems include:

g   Automatically closing or remotely operated valves
g   Sprays and deluge systems
g   Relief valves
g   Check valves
g   Excess flow valves
g   Scrubbers

The predicted frequency of occurrence of the worst-case scenario is not an allowable
consideration. You are not required to determine a possible cause of the failure of
the vessel or pipe.

GENERAL REQUIREMENTS FOR FLAMMABLE SUBSTANCES

As for toxic substances, the worst-case release quantity Q is either the greatest
amount held in a single vessel or the greatest amount in a pipe. In both cases, you
may take into account administrative controls that limit the maximum capacity. In
the case of the vessel, you need only take into account the quantity in the vessel,
regardless of any connections with other vessels.

The worst-case analysis assumes the quantity vaporizes. There is a vapor cloud
explosion. If you use a TNT-equivalent model to determine the distance to the
endpoint, you must assume that 10 percent of the total quantity is involved in the
explosion (that is, the yield factor is 10 percent).

You must determine the distance to the explosion endpoint; that is, the distance at
which there is an overpressure of 1 psi (the farthest distance from the point of release
at which the explosion causes the pressure on a person or building to exceed
atmospheric pressure by 1 psi).

CHLORINE

At WWTPs, chlorine is most likely to be present in 150-lb cylinders, in one-ton (2,000-lb) cylinders, in 17-ton tank trucks, or in 90-ton railcars. The worst-case scenario assumes that these quantities are completely released over a period of 10 minutes (e.g., a 150-lb worst case corresponds to a 15-lb/min rate of release). The predicted distances to the toxic endpoint for each of these scenarios is given in Exhibit 4-3. These distances are for releases that are assumed to take place outdoors. See Section 4.3 for a discussion on buildings.

EXHIBIT 4-3
DISTANCES TO TOXIC ENDPOINTS - CHLORINE
F Stability, Wind Speed 1.5 Meters per Second

Scenario	Release Rate (lb/min)	Distance to Toxic Endpoint (miles)	
		Rural	**Urban**
150-lb cylinder	15	0.8	0.4
1-ton cylinder	200	3.0	1.3
17-ton tank trucks	3,400	12	5.8
90-ton railcar	18,000	> 25	14

If your facility does not fit into the standard pattern of 150-lb cylinders, one-ton cylinders, 17-ton tank trucks, or 90-ton railcars, you should use Figure 4-1 or Exhibit 4-4. Identify the chlorine vessel that contains the largest quantity of any in your facility and divide that mass by 10 to obtain the release rate in lb/min. Look for that release rate, or the rate nearest to it, in Exhibit 4-4. Then read across to the rural or urban distances.

Alternatively, look along the bottom axis of Figure 4-1, read up to the curve(s) and then across to the corresponding distances on the vertical axis.

As noted above, the results presented in Exhibit 4-3 and 4-4 are for a release that is outside. Many of you will keep your chlorine vessels inside buildings. Some will even have specially designed, leak-tight buildings with chlorine or sulfur dioxide scrubbers. However, the intention of this section is to provide information on the worst-case scenario. There are times when you will be handling the cylinders outside. Nevertheless, in discussions with local agencies and local communities you may well want to explain how your facility is designed to prevent or mitigate worst-case scenarios.

EXHIBIT 4-4
DISTANCES TO TOXIC ENDPOINT FOR CHLORINE
F Stability, Wind Speed 1.5 Meters per Second

Release Rate (lbs/min)	Distance to Endpoint (miles)		Release Rate (lbs/min)	Distance to Endpoint (miles)	
	Rural	Urban		Rural	Urban
1	0.2	0.1	750	5.8	2.6
2	0.3	0.1	800	5.9	2.7
5	0.5	0.2	900	6.3	2.9
10	0.7	0.3	1,000	6.6	3.0
15	0.8	0.4	1,500	8.1	3.8
20	1.0	0.4	2,000	9.3	4.4
30	1.2	0.5	2,500	10	4.9
40	1.4	0.6	3,000	11	5.4
50	1.5	0.6	4,000	13	6.2
60	1.7	0.7	5,000	14	7.0
70	1.8	0.8	6,000	16	7.6
80	1.9	0.8	7,000	17	8.3
90	2.0	0.9	7,500	18	8.6
100	2.2	0.9	8,000	18	8.9
150	2.6	1.2	9,000	19	9.4
200	3.0	1.3	10,000	20	9.9
250	3.4	1.5	15,000	25	12
300	3.7	1.6	20,000	*	14
400	4.2	1.9	25,000	*	16
500	4.7	2.1	30,000	*	18
600	5.2	2.3	40,000	*	20
700	5.6	2.5	50,000	*	*

* More than 25 miles (report distance as 25 miles)

These are results that you can simply quote when you submit your RMP.

SULFUR DIOXIDE

Sulfur dioxide, if present at a WWTP, is also likely to be in 150-lb cylinders, one-ton cylinders, 17-ton tank cars, or 90-ton railcars. The worst-case scenario assumes that these quantities are completely released over a period of 10 minutes. The predicted distances to the toxic endpoint for each of these scenarios is given in Exhibit 4-5.

EXHIBIT 4-5
DISTANCES TO TOXIC ENDPOINT - SULFUR DIOXIDE
F Stability, Wind Speed 1.5 Meters per Second

Scenario	Release Rate (lb/min)	Distance to Toxic Endpoint (miles)	
		Rural	**Urban**
150-lb cylinder	15	0.7	0.3
1-ton cylinder	200	3.1	1.3
17-ton tank trucks	3,400	15	6.0
90-ton railcar	18,000	> 25	15

These are results that you can simply quote when you submit your RMP.

If your facility does not fit into the standard pattern of 150-lb cylinders, one-ton cylinders, or 90-ton railcars, you should use Figure 4-2 or Exhibit 4-6. Identify the sulfur dioxide vessel that contains the largest quantity of any in your facility. Divide that quantity by 10 to obtain the release rate in lb/min and look for that rate, or the rate nearest to it, on Exhibit 4-6. Then read across to the rural or urban distances. Alternatively, use Figure 4-2.

EXHIBIT 4-6
DISTANCES TO TOXIC ENDPOINT FOR SULFUR DIOXIDE
F Stability, Wind Speed 1.5 Meters per Second

Release Rate (lbs/min)	Distance to Endpoint (miles)		Release Rate (lbs/min)	Distance to Endpoint (miles)	
	Rural	Urban		Rural	Urban
1	0.2	0.1	750	6.6	2.6
2	0.2	0.1	800	6.8	2.7
5	0.4	0.2	900	7.2	2.9
10	0.6	0.2	1,000	7.7	3.1
15	0.7	0.3	1,500	9.6	3.8
20	0.9	0.4	2,000	11	4.5
30	1.1	0.5	2,500	13	5.0
40	1.3	0.5	3,000	14	5.6
50	1.4	0.6	4,000	17	6.5
60	1.6	0.7	5,000	19	7.3
70	1.8	0.7	6,000	21	8.1
80	1.9	0.8	7,000	23	8.8
90	2.0	0.8	7,500	24	9.1
100	2.1	0.9	8,000	25	9.5
150	2.7	1.1	9,000	*	10
200	3.1	1.3	10,000	*	11
250	3.6	1.4	15,000	*	13
300	3.9	1.6	20,000	*	16
400	4.6	1.9	25,000	*	18
500	5.2	2.1	30,000	*	19
600	5.8	2.3	40,000	*	23
700	6.3	2.5	50,000	*	*

* More than 25 miles (report distance as 25 miles)

ANHYDROUS AMMONIA

In WWTPs, anhydrous ammonia is generally stored as a liquid under pressure in vessels that are kept outdoors. These vessels are relatively large (e.g., 10,000 gallons or . 56,000 lb) . Identify the quantity of ammonia in your storage vessel and divide by 10 to obtain the release rate in lb/min. Look for that release rate, or the release rate nearest to it, on Exhibit 4-7. Then read across to the rural or urban distances. Alternatively, use Figure 4-3.

The 10,000-gallon vessel mentioned above contains 56,000 lb when full. (You may take into account any administrative controls that limit the quantity of the ammonia in the vessel. For example, you will generally require that the vessel never be filled above 85 percent of its total volume to allow for the high coefficient of volumetric expansion of ammonia.) Assuming for the sake of the present example that 56,000 lb is the greatest quantity of ammonia that will ever be in the vessel, the release rate is 5,600 lb/min. The closest release rate on Exhibit 4-7 is 6,000 lb/min. The corresponding rural distance is approximately 4.4 miles and the corresponding urban distance is approximately 2.8 miles.

EXHIBIT 4-7
DISTANCES TO TOXIC ENDPOINT
FOR ANHYDROUS AMMONIA LIQUEFIED UNDER PRESSURE
F Stability, Wind Speed 1.5 Meters per Second

Release Rate (lbs/min)	Distance to Endpoint (miles)		Release Rate (lbs/min)	Distance to Endpoint (miles)	
	Rural	Urban		Rural	Urban
1	0.1	0.1	1,000	1.8	1.2
2	0.1	0.1	1,500	2.2	1.5
5	0.1	0.1	2,000	2.6	1.7
10	0.2	0.1	2,500	2.9	1.9
15	0.2	0.2	3,000	3.1	2.0
20	0.3	0.2	4,000	3.6	2.3
30	0.3	0.2	5,000	4.0	2.6
40	0.4	0.3	6,000	4.4	2.8
50	0.4	0.3	7,000	4.7	3.1
60	0.5	0.3	7,500	4.9	3.2
70	0.5	0.3	8,000	5.1	3.3
80	0.5	0.4	9,000	5.4	3.4
90	0.6	0.4	10,000	5.6	3.6
100	0.6	0.4	15,000	6.9	4.4
150	0.7	0.5	20,000	8.0	5.0
200	0.8	0.6	25,000	8.9	5.6
250	0.9	0.6	30,000	9.7	6.1
300	1.0	0.7	40,000	11	7.0
400	1.2	0.8	50,000	12	7.8
500	1.3	0.9	75,000	15	9.5
600	1.4	0.9	100,000	18	10
700	1.5	1.0	150,000	22	13
750	1.6	1.0	200,000	*	15
800	1.6	1.1	250,000	*	17
900	1.7	1.2	750,000	*	*

* More than 25 miles (report distance as 25 miles)

AQUEOUS AMMONIA

Some WWTPs keep aqueous ammonia in outside storage tanks at atmospheric pressure. The tanks usually stand in a diked area. Commercial grades of aqueous ammonia vary from less than 20 weight percent to about 30 weight percent. For ease of presentation, the ammonia is assumed to be in a 30 weight percent solution. Because this has the highest vapor pressure of any of the commercial grades used in wastewater treatment facilities, its use is conservative if you have aqueous ammonia in a less than 30 weight percent solution.

If there is a catastrophic failure, the aqueous ammonia will spill into the diked area.

You are allowed to consider the dike, which is a passive mitigation feature. However, if you have any reason to believe that the dike will not withstand the event that leads to the spill, or if your tank does not stand in a diked area, then you should assume, as required by the rule, that the spill spreads out until its depth is only 1 cm (0.39 inch). The first step is to calculate the rate of evaporation from the pool.

UNDIKED AREA

For an undiked area, the rate of release of ammonia from the pool (QR) (lb/min) is given by:

$$QR = 0.020QS \tag{1}$$

where QS is the total quantity (lb) of the spill of aqueous ammonia. For example, if there is a spillage of 80,000 lb, the rate of evaporation is 0.02 x 80,000 = 1,600 lb/min. The present guidance assumes that this is the average rate of release over 10 minutes, after which the pool will be more dilute than it was initially and will be evaporating much less rapidly.

DIKED AREA

For a diked area, the rate of evaporation is:

$$QR = 0.036A_p \tag{2}$$

where A_p is the diked area in square feet. For example, if the vessel stands in a diked area that is 40 feet x 40 feet = 1,600 ft^2, the predicted rate of evaporation is 0.036 x 1,600 = 58 lb/min.

The maximum area of the pool that would be formed by the spilled liquid can be estimated as 0.55QS. If you have a diked area that is larger than the maximum area, use Equation 1 for an undiked area to estimate the release rate to air.

RATES OF RELEASE AT TEMPERATURES OTHER THAN 25 °C

The actual temperature of stored aqueous ammonia varies with the ambient temperature. The rule requires you to consider the release temperature to be the

highest daily temperature observed during the last three years, or the operating temperature, whichever is highest. The ratio $R_{vp}(T)$ represents the ratio of the partial pressure of ammonia at temperature T ºC to the partial pressure at 25 ºC.

Exhibit 4-8 gives values of $R_{vp}(T)$ for 30 percent aqueous ammonia in 1 ºC increments from 15 ºC to 40 ºC (59 ºF to 104 ºF). The rates of evaporation in Equations 1 and 2 are proportional to the vapor pressure, so to obtain a rate of evaporation for a temperature T ºC other than 25 ºC, simply multiply the right-hand side of Equation 1 or 2 by the corresponding value of $R_{vp}(T)$. For example, for an undiked release of 80,000 lbs of ammonia at 35 ºC, the calculation is (0.020)(80,000)(1.45) = 2,300 lbs/min.

The vapor pressure of ammonia at other temperatures can be obtained from the *Handbook of Chemistry and Physics*, CRC Press, 1998.

DISTANCES TO TOXIC ENDPOINT

Take the evaporation rate and look for that rate, or the rate nearest to it, on Exhibit 4-9. Then read across to the rural or urban distances. For example, for the 58 lb/min release rate derived above, the closest release rate on Exhibit 4-9 is 60 lb/min. The predicted rural distance is approximately 0.4 mile and the predicted urban distance is approximately 0.2 mile. Alternatively, use Figure 4-4.

EXHIBIT 4-8
RATIO OF VAPOR PRESSURE OF AMMONIA IN 30% AQUEOUS AMMONIA
(Ratio is Unity at 25 ⁰C)

Temperature T (ºC)	Ratio $R_{vp}(T)$	Temperature T (ºC)	Ratio $R_{vp}(T)$
15	0.67	28	1.12
16	0.70	29	1.16
17	0.73	30	1.21
18	0.76	31	1.25
19	0.79	32	1.30
20	0.82	33	1.35
21	0.86	34	1.40
22	0.89	35	1.45
23	0.93	36	1.50
24	0.96	37	1.55
25	1.00	38	1.61
26	1.04	39	1.66
27	1.08	40	1.72

EXHIBIT 4-9
DISTANCES TO TOXIC ENDPOINT FOR AQUEOUS AMMONIA
F Stability, Wind Speed 1.5 Meters per Second

Release Rate (lbs/min)	Distance to Endpoint (miles)		Release Rate (lbs/min)	Distance to Endpoint (miles)	
	Rural	Urban		Rural	Urban
1	0.1	0.1	1,000	1.6	0.6
2	0.1	0.1	1,500	2.0	0.7
5	0.1	0.1	2,000	2.2	0.8
10	0.2	0.1	2,500	2.5	0.9
15	0.2	0.1	3,000	2.7	1.0
20	0.3	0.1	4,000	3.1	1.1
30	0.3	0.1	5,000	3.4	1.2
40	0.4	0.1	6,000	3.7	1.3
50	0.4	0.1	7,000	4.0	1.4
60	0.4	0.2	7,500	4.1	1.5
70	0.5	0.2	8,000	4.2	1.5
80	0.5	0.2	9,000	4.5	1.6
90	0.5	0.2	10,000	4.7	1.7
100	0.6	0.2	15,000	5.6	2.0
150	0.7	0.2	20,000	6.5	2.4
200	0.8	0.3	25,000	7.2	2.6
250	0.8	0.3	30,000	7.8	2.8
300	0.9	0.3	40,000	8.9	3.3
400	1.1	0.4	50,000	9.8	3.6
500	1.2	0.4	75,000	12	4.4
600	1.3	0.4	100,000	14	5.0
700	1.4	0.5	150,000	16	6.1
750	1.4	0.5	200,000	19	7.0
800	1.5	0.5	250,000	21	7.8
900	1.5	0.6	750,000	*	13

* More than 25 miles (report distance as 25 miles)

METHANE

Methane is present at some wastewater treatment facilities as a component of digester gas. Typical constituents of digester gas are 55 to 70 percent methane by volume, 25 to 30 percent carbon dioxide by volume, and small amounts of nitrogen and hydrogen. Modern facilities may well have processes containing more than 10,000 lb of digester gas at any one time (the entire quantity of the flammable mixture in a process must be compared with the threshold quantity (TQ) of 10,000 lb to determine whether the facility is covered). Proceed as follows:

1.   Determine the density D_m of the methane in the digester at operating temperature T (^{o}F), assuming that there is X vol percent of methane and 100 - X vol percent of carbon dioxide and other materials. You should determine X by analysis of your digester gas; if you do not know the percentage of methane, you may use 70 percent as a conservative assumption. If X varies over time, you should use the largest value of X that is seen in your facility.

$$D_m = 0.22 \ X/(460+T) \tag{3}$$

As an example, if X = 65, and the operating temperature is 95 ^{o}F, $D_m = 0.026$ lb/ft^3.

2.   Calculate the total volume V (ft^3) occupied by digester gas in one digester (the largest). Associated pipework can be neglected.

$$V = Br^2H \tag{4}$$

Here, r is the digester radius and H is the maximum digester head space. As an example, if H = 8 ft and r = 40 ft, then $V = Br^2H = (3.14)(40)^2(8)$. 40,200 ft^3.

3.   Calculate the quantity Q of methane contained in V:

$$Q = D_mV \tag{5}$$

In the current example, Q = (0.026)(40,200) = 1,045 lb

Note that this quantity of methane itself, as well as the total quantity of digester gas, is less than the 10,000-lb TQ for flammable materials. This is because the total amount of digester gas (i.e., not just methane) in a process is used to determine whether that process is covered by the regulation. It may be the case that no single digester contains more than the TQ of digester gas, but you are covered because there are several digesters in your process. However, you are required to consider only the quantity of methane in a single vessel when calculating the results of a worst-case vapor cloud explosion.

4. Use the TNT-equivalency model to calculate the distance D (miles) to the 1 psi overpressure endpoint:

$$D = 0.0082 \, (Q)^{1/3} \qquad (6)$$

Equation 6 has been customized for methane. In the present example, $D = 0.0082(1,045)^{1/3}$. 0.08 mile. Alternatively, you can use Exhibit 4-10 to estimate the distance to the endpoint for a range of quantities of methane.

EXHIBIT 4-10
DISTANCE TO OVERPRESSURE ENDPOINT OF 1.0 PSI FOR VAPOR CLOUD EXPLOSIONS OF METHANE
Based on TNT Equivalent Method, 10 Percent Yield Factor

Quantity in Cloud (pounds)	Distance to Endpoint (miles)	Quantity in Cloud (pounds)	Distance to Endpoint (miles)
500	0.07	50,000	0.3
2,000	0.1	100,000	0.4
5,000	0.1	200,000	0.5
10,000	0.2	500,000	0.7
20,000	0.2	1,000,000	0.8

Some facilities have an intermediate storage vessel for digester gas, at a pressure that may be typically 45-50 psig. You should use the quantity of methane in such a vessel in Equation 6 or Exhibit 4-10 if it contains the largest quantity of digester gas on site.

4.2   ALTERNATIVE SCENARIOS

This section provides guidance on how to choose and model alternative scenarios. Information is provided on the general requirements of the regulations, followed by specific sections on chlorine, sulfur dioxide, anhydrous ammonia, aqueous ammonia, and methane.

GENERAL REQUIREMENTS

The requirements that differ from those for worst-case scenarios are as follows:

g   You can take into account active as well as passive mitigation systems, as long as these systems are expected to withstand the causes of the accident.

g   <u>The alternative scenario should reach an endpoint offsite</u>, unless no such scenario exists.

g   If you are doing your own modeling, you should use "typical meteorological conditions for the stationary source." You may obtain these data from local weather stations. You can obtain wind speed and temperature data from the National Climatic Data Center at (828) 271-4800. This guidance uses an "average" weather condition of wind speed 3 m/s and D stability class with an ambient temperature of 25 °C.

g   The number of alternative scenarios you are required to develop is as follows:

   í   At least one scenario for each regulated toxic substance held in Program 2 and Program 3 processes.
   í   At least one scenario to represent all flammables held in Program 2 and Program 3 processes.

Thus, if you have anhydrous ammonia, chlorine, sulfur dioxide, and digester gas on your site in Program 2 and Program 3 processes, you will need, at a minimum, three alternative toxic scenarios, one each for ammonia, chlorine and sulfur dioxide, but only one alternative flammable scenario, for digester gas.

CHOICE OF ALTERNATIVE SCENARIOS

Your alternative scenario for a covered process must be one that is more likely to occur than the worst-case scenario and that reaches an endpoint offsite, unless no such scenario exists. You do not need to demonstrate greater likelihood of occurrence or carry out any analysis of probability of occurrence; you only need to use reasonable judgement and knowledge of the process. If, using a combination of reasonable assumptions, modeling of a release of a regulated substance from a process shows that the relevant endpoint is not reached offsite, you can use the modeling results to demonstrate that a scenario does not exist for the process that will give an endpoint offsite. You must report an alternative scenario, however.

Release scenarios you should consider include, but are not limited to, the following, where applicable:

g   Transfer hose releases due to splits or sudden uncoupling;
g   Process piping releases from failures at flanges, joints, welds, valves and valve seals, and drains or bleeds;
g   Process vessel or pump releases due to cracks, seal failure, drain bleed, or plug failure;
g   Vessel overfilling and spill, or overpressurization and venting through relief valves or rupture disks; and
g   Shipping container mishandling and breakage or puncturing leading to a spill.

For alternative release scenarios, you may consider active mitigation systems, such as interlocks, shutdown systems, pressure relieving devices, flares, emergency isolation systems, and fire water and deluge systems, as well as passive mitigation systems. Mitigation systems considered must be capable of withstanding the event that triggers the release while remaining functional.

You must consider your five-year accident history and failure scenarios identified in your hazard review or process hazards analysis in selecting alternative release scenarios for regulated toxic or flammable substances (e.g., you might choose an actual event from your accident history as the basis of your scenario). You also may consider any other reasonable scenarios.

The alternative scenarios you choose to analyze should be scenarios that you consider possible at your site. Although EPA requires no explanation of your choice of scenario, you should choose a scenario that you think you can explain to emergency responders and the public as a reasonable alternative to the worst-case scenario. For example, you could pick a scenario based on an actual event, or you could choose a scenario that you worry about, because circumstances at your site might make it a possibility. If you believe that there is no reasonable scenario that could lead to offsite consequences, you may use a scenario that has no offsite impacts for your alternative analysis. You should be prepared to explain your choice of such a scenario to the public, should questions arise.

WWTP SCENARIOS

A number of scenarios other than those listed in the rule may be worth considering for WTTPs. Many WWTPs have single-stage, pass-through chemical scrubbers to neutralize compounds such as sulfur dioxide. Failure of the neutralizing solution's recirculation pump and continued operation of the blower fan could not only allow a release, but also exacerbate it by mechanically evacuating the substance from the room.

Accidents reported to EPA involving chlorine systems have been caused by "rust holes," failure of a diaphragm, leak during hookup to a tank, a packing nut leak, faulty cylinders, removal of a valve in error, faulty valves, leaking gaskets, and a blown pressure gauge. Similar accidents involving sulfur dioxide systems have been

reported. In addition, natural events, such as floods, tornados, earthquakes, and hurricanes could cause several releases to occur simultaneously. You may want to consider these types of scenarios when you select your alternative release scenarios.

CHLORINE

FLASHING LIQUID RELEASES

Many of the potential alternative scenarios could involve the release of liquid chlorine from a small hole. The liquid chlorine flashes immediately to vapor and fine liquid droplets and is carried downwind.

The rate of release of a liquid through an hole is given by Bernoulli's formula for liquid releases (see Appendix 4A). Using chemical-specific data for chlorine, the formula becomes:

$$QR = 3,140 \times A_h \qquad\qquad (8)$$

where:

A_h	=	the area of the hole (in^2 - for example, the area of a hole of diameter 1 inch is 0.785 in^2)
$3,140$ =		factor applicable to chlorine liquefied under a pressure of 98.5 psig (see Appendix 4A)

Note that this is the formula for the release of a pure liquid and would apply to a breach in the wall of a vessel or to the rupture of a very short pipe. For long pipes, there is a pressure drop between the vessel and the hole, and there will be flashing in the pipe and a reduced rate of release. Therefore, Equation 8 may be conservative.

If there is a small leak from the liquid space of a large storage vessel, the reservoir can essentially be considered as infinite, and the chlorine will be steadily emitted at a constant rate for a relatively long period. Such leaks may occur because of a gasket failure, a pump seal leak, or a corrosion hole, for example. You can use Equation 8 and the estimated area of the hole to calculate the release rate (QR).

To predict the distance to the toxic endpoint, take the calculated value of QR and identify the closest value on Exhibit 4-11 (150 lb/min). Read off the corresponding distance, in this case, 0.6 mile for a rural site and 0.2 mile for an urban site. Alternatively, use Figure 4-5.

Exhibit 4-12 provides release rate estimates for releases of liquid chlorine through holes of diameter 1/16 inch to 5 inches and the distances to the endpoint corresponding to these release rates. You can use this table instead of Equation 8 and Exhibit 4-11 to estimate the distance to the endpoint.

EXHIBIT 4-11
DISTANCES TO TOXIC ENDPOINT FOR CHLORINE
D Stability, Wind Speed 3 Meters per Second

Release Rate (lbs/min)	Distance to Endpoint (miles)		Release Rate (lbs/min)	Distance to Endpoint (miles)	
	Rural	Urban		Rural	Urban
1	0.1	0.1	750	1.2	0.4
2	0.1		800	1.2	0.5
5	0.1		900	1.2	0.5
10	0.2	0.1	1,000	1.3	0.5
15	0.2	0.1	1,500	1.6	0.6
20	0.2	0.1	2,000	1.8	0.6
30	0.3	0.1	2,500	2.0	0.7
40	0.3	0.1	3,000	2.2	0.8
50	0.3	0.1	4,000	2.5	0.8
60	0.4	0.2	5,000	2.8	0.9
70	0.4	0.2	7,500	3.4	1.2
80	0.4	0.2	10,000	3.9	1.3
90	0.4	0.2	15,000	4.6	1.6
100	0.5	0.2	20,000	5.3	1.8
150	0.6	0.2	25,000	5.9	2.0
200	0.6	0.3	30,000	6.4	2.1
250	0.7	0.3	40,000	7.3	2.4
300	0.8	0.3	50,000	8.1	2.7
400	0.8	0.4	75,000	9.8	3.2
500	1.0	0.4	100,000	11	3.6
600	1.0	0.4	150,000	13	4.2
700	1.1	0.4	200,000	15	4.8

EXHIBIT 4-12
RELEASE RATES AND DISTANCE TO THE ENDPOINT FOR LIQUID CHLORINE RELEASES
D Stability, Wind Speed 3 Meters per Second

Hole Diameter (inches)	Release Rate (lb/min)	Distance (miles)	
		Rural	**Urban**
1/16	10	0.2	0.1
3/16	87	0.4	0.2
1/4	150	0.6	0.2
5/16	240	0.7	0.3
½	620	1.0	0.4
1	2,500	2.0	0.7
2	9,900	3.9	1.3
3	22,200	5.3	1.8
4	39,500	7.3	2.4
5	61,700	8.1	2.7

TWO-PHASE RELEASES

In case of a release from a long pipe carrying liquid chlorine ($L/d_h \gg 1$, where L is the length of the pipe between the reservoir of chlorine and the atmosphere and d_h is the diameter of the pipe), there can be flashing in the discharge pipe, resulting in a two-phase mixture emerging to the atmosphere. In this case, the rate of release in lb/min for chlorine is given by:

$$QR = 1,100 \times A_h \times F \tag{9}$$

where:

1,100 =		chemical-specific factor applicable to chlorine at 25 °C (see Appendix 4A)
A_h	=	hole area (in^2) = area of pipe opening
F	=	frictional loss factor (dimensionless) with values as follows:

F	L/d_h
1	10
0.85	50
0.75	100
0.65	200
0.55	400

Exhibit 4-13 presents release rates for a range of pipe diameters and length-diameter ratios for two-phase releases of chlorine from a pipe. You can read the release rate from the exhibit or calculate the release rate from Equation 10, then find the distance to the endpoint corresponding to the release rate by referring to Exhibit 4-11.

EXHIBIT 4-13
RELEASE RATES FOR TWO-PHASE RELEASES FROM PIPES CARRYING LIQUID CHLORINE

Pipe Diameter (inches)	Pipe Length/Diameter (L/d_h)				
	10 (F=1)	50 (F=0.85)	100 (F=0.75)	200 (F=0.65)	400 (F=0.55)
	Chlorine Release Rate (lbs/min)				
1/4	54	46	40	35	30
5/16	84	72	63	55	46
½	220	180	160	85,800	120
3/4	490	410	360	320	270
1	860	730	650	560	480
2	3,500	2,900	2,600	2,200	1,900
3	7,800	6,600	5,800	5,100	4,300

VAPOR RELEASES

For a choked release of vapor (i.e., emerging at the speed of sound from the hole, which will invariably be the case for chlorine at atmospheric temperatures), the release rate for chlorine is given by:

$$QR = 190 \times A_h \tag{10}$$

where:

190	=	chemical-specific factor for chlorine at a tank pressure of 113 psia and temperature 25 ºC (see Appendix 4A)
A_h	=	hole area (in^2)

You can use Equation 10 to estimate the release rate of chlorine from a hole in the vapor space of a tank. For example, such a hole could result from shearing off a valve at the top of a tank. The distance to the endpoint can be estimated from the release rate, using Exhibit 4-11 or 4-5.

As an alternative to Equation 10, for releases from holes ranging from 1/16-inch to 5 inches in diameter, you can read the release rate and the corresponding distance from Exhibit 4-14.

EXHIBIT 4-14
RELEASE RATES AND DISTANCE TO THE ENDPOINT FOR CHLORINE VAPOR RELEASES
D Stability, Wind Speed 3 Meters per Second

Hole Diameter (inches)	Release Rate (lbs/min)	Distance (miles)	
		Rural	Urban
1/16	0.6	0.1	0.1
3/16	5	0.1	0.1
1/4	9	0.2	0.1
5/16	15	0.2	0.1
½	37	0.3	0.1
1	150	0.6	0.2
2	600	1.0	0.4
3	1,300	1.6	0.6
4	2,400	2.0	0.7
5	3,700	2.5	0.8

Note that the release rate estimated by the method above is conservative. As the release proceeds, chlorine continuously evaporates from the liquid surface in the cylinder. This causes the liquid to cool, the vapor pressure to decrease, and the rate of release to decline. However, the equations for calculating this effect are rather complex and not included in this guidance.

OTHER CHLORINE SCENARIOS

If you wish to do so, you can simply quote any of the results above, if they are applicable to your site, when you submit your Risk Management Plan. However, you may also choose to develop other scenarios, using Equations 8, 9, or 10, and Exhibit 4-11 or Figure 4-5.

DURATION OF RELEASE

You may calculate the maximum duration by dividing the quantity in the tank or the quantity that would be released from a pipe by the release rate. You may use 60 minutes as a default value for maximum release duration. If you know, and can substantiate, how long it is likely to take to stop the release, you may use that time as the release duration.

SULFUR DIOXIDE

FLASHING LIQUID RELEASES

Sulfur dioxide is similar to chlorine in the way that it would be released, so Bernoulli's formula is applicable. Using Bernoulli's formula, incorporating chemical-specific data for sulfur dioxide, you can estimate the release rate from a hole in the liquid space of a tank from the following equation:

$$QR = 2{,}020 \times A_h \qquad\qquad (11)$$

where:

A_h	=	the area of the hole (in^2)
$2{,}020$ =		factor applicable to sulfur dioxide liquefied under a pressure of 43 psig (see Appendix 4A)

After you have estimated the release rate, you can find the predicted distance to the toxic endpoint for sulfur dioxide from Exhibit 4-16 (next page) or Figure 4-6.

Alternatively, you can use Exhibit 4-15. This exhibit gives release rates and distances to the endpoint for flashing liquid releases through holes of diameter 1/16 inch to 5 inches.

EXHIBIT 4-15
RELEASE RATES AND DISTANCE TO THE ENDPOINT FOR LIQUID SULFUR DIOXIDE RELEASES
D Stability, Wind Speed 3 Meters per Second

Hole Diameter (inches)	Release Rate (lb/min)	Distance (miles)	
		Rural	Urban
1/16	6	0.1	0.1
3/16	56	0.4	0.2
1/4	99	0.5	0.2
5/16	160	0.6	0.2
½	400	0.9	0.4
1	1,600	1.9	0.6
2	6,300	3.3	1.1
3	14,300	5.6	1.7
4	25,300	7.3	2.1
5	39,600	9.2	2.6

EXHIBIT 4-16
DISTANCES TO TOXIC ENDPOINT FOR SULFUR DIOXIDE
D Stability, Wind Speed 3 Meters per Second

Release Rate (lbs/min)	Distance to Endpoint (miles)		Release Rate (lbs/min)	Distance to Endpoint (miles)	
	Rural	Urban		Rural	Urban
1	0.1	0.1	750	1.3	0.5
2	0.1		800	1.3	0.5
5	0.1		900	1.4	0.5
10	0.2	0.1	1,000	1.5	0.5
15	0.2	0.1	1,500	1.9	0.6
20	0.2	0.1	2,000	2.2	0.7
30	0.2	0.1	2,500	2.3	0.8
40	0.3	0.1	3,000	2.7	0.8
50	0.3	0.1	4,000	3.1	1.0
60	0.4	0.2	5,000	3.3	1.1
70	0.4	0.2	7,500	4.0	1.3
80	0.4	0.2	10,000	4.6	1.4
90	0.4	0.2	15,000	5.6	1.7
100	0.5	0.2	20,000	6.5	1.9
150	0.6	0.2	25,000	7.3	2.1
200	0.6	0.2	30,000	8.0	2.3
250	0.7	0.3	40,000	9.2	2.6
300	0.8	0.3	50,000	10	2.9
400	0.9	0.4	75,000	13	3.5
500	1.0	0.4	100,000	14	4.0
600	1.1	0.4	150,000	18	4.7
700	1.2	0.4	200,000	20	5.4

TWO-PHASE RELEASES

A break in a long pipe (whose length is much greater than its diameter) carrying liquid sulfur dioxide can result in the release of a two-phase mixture, as discussed above for chlorine. The release rate can be estimated from the following equation:

$$QR = 252 \times A_h \times F \tag{12}$$

where:

252   =   chemical-specific factor applicable to sulfur dioxide at 25 °C (see Appendix 4A)

A_h =   hole area (in^2) = area of pipe opening

F   =   frictional loss factor (dimensionless) with values as shown in the section on chlorine

You can estimate the release rate from Equation 12, then find the distance to the endpoint corresponding to the release rate by referring to Exhibit 4-11. You also can find the release rate for a range of pipe diameters and L/d_h values in Exhibit 4-17.

EXHIBIT 4-17
RELEASE RATES FOR TWO-PHASE RELEASES FROM PIPES CARRYING LIQUID SULFUR DIOXIDE

Pipe Diameter (inches)	Pipe Length/Diameter (L/d_h)				
	10 (F=1)	50 (F=0.85)	100 (F=0.75)	200 (F=0.65)	400 (F=0.55)
	Sulfur Dioxide Release Rate (lbs/min)				
1/4	12	11	9	8	7
5/16	19	16	14	13	11
½	49	42	37	32	27
3/4	110	95	83	72	61
1	200	170	150	130	110
2	800	670	600	520	440
3	1,800	1,500	1,300	1,200	980

VAPOR RELEASES

For a choked release of sulfur dioxide vapor, the release rate is given:

$$QR = 91 \times A_h \tag{13}$$

where:

91   =   chemical-specific factor for sulfur dioxide at a tank pressure of 58 psia and temperature 25 °C (see Appendix 4A)

A_h =   hole area (in^2)

The distance to the endpoint can be estimated from the release rate, using Exhibit 4-16 or Figure 4-6.

As an alternative to Equation 13 and Exhibit 4-16, for releases from holes ranging from 1/4 inch to 5 inches in diameter, you can read the release rate and the corresponding distance from Exhibit 4-18.

EXHIBIT 4-18
**RELEASE RATES AND DISTANCE TO THE ENDPOINT FOR SULFUR DIOXIDE VAPOR
RELEASES**
D Stability, Wind Speed 3 Meters per Second

Hole Diameter (inches)	Release Rate (lbs/min)	Distance (miles)	
		Rural	Urban
1/4	4	0.1	0.1
5/16	7	0.1	0.1
½	18	0.2	0.1
1	71	0.4	0.2
2	280	0.8	0.3
3	640	1.1	0.4
4	1,100	1.5	0.5
5	1,800	2.2	0.7

OTHER SULFUR DIOXIDE SCENARIOS

If you wish to do so, you can simply quote any of the results above, if they are
applicable to your site, when you submit your Risk Management Plan. However,
you may also choose to develop other scenarios, using Equations 11, 12, or 13, and
Exhibit 4-16 or Figure 4-6.

ANHYDROUS AMMONIA

FLASHING LIQUID RELEASES

Like chlorine and sulfur dioxide, ammonia will be liquefied under pressure in its own storage vessel. Bernoulli's equation is applicable for flashing liquid releases (see Appendix 4A). The equation for ammonia liquefied under a pressure of 130 psig is:

$$QR = 2,380 \times A_h \tag{14}$$

where:

A_h	=	hole area (in^2)
2,380	=	chemical-specific factor for ammonia liquefied under pressure

After you have estimated the release rate, you can find the predicted distance to the toxic endpoint for ammonia from Exhibit 4-20 (next page) or Figure 4-7.

Alternatively, you can use Exhibit 4-19. This exhibit gives release rates and distances to the endpoint for flashing liquid releases through holes of diameter 1/16 inch to 5 inches.

EXHIBIT 4-19
RELEASE RATES AND DISTANCE TO THE ENDPOINT FOR LIQUID AMMONIA RELEASES
D Stability, Wind Speed 3 Meters per Second

Hole Diameter (inches)	Release Rate (lbs/min)	Distance (miles)	
		Rural	Urban
1/16	7	0.1	0.1
3/16	66	0.2	0.1
1/4	120	0.2	0.1
5/16	180	0.4	0.2
½	470	0.4	0.2
1	1,900	0.8	0.3
2	7,500	1.6	0.5
3	16,800	2.2	0.7
4	30,000	3.1	1.0
5	46,800	3.9	1.2

EXHIBIT 4-20
DISTANCES TO TOXIC ENDPOINT FOR ANHYDROUS AMMONIA
D Stability, Wind Speed 3 Meters per Second

Release Rate (lbs/min)	Distance to Endpoint (miles)		Release Rate (lbs/min)	Distance to Endpoint (miles)	
	Rural	Urban		Rural	Urban
<10	0.1	0.1	900	0.6	0.2
10	0.1		1,000	0.6	0.2
15	0.1		1,500	0.7	0.3
20	0.1		2,000	0.8	0.3
30	0.1		2,500	0.9	0.3
40	0.1		3,000	1.0	0.4
50	0.1		4,000	1.2	0.4
60	0.2	0.1	5,000	1.3	0.5
70	0.2	0.1	7,500	1.6	0.5
80	0.2	0.1	10,000	1.8	0.6
90	0.2	0.1	15,000	2.2	0.7
100	0.2	0.1	20,000	2.5	0.8
150	0.2	0.1	25,000	2.8	0.9
200	0.3	0.1	30,000	3.1	1.0
250	0.3	0.1	40,000	3.5	1.1
300	0.3	0.1	50,000	3.9	1.2
400	0.4	0.2	75,000	4.8	1.4
500	0.4	0.2	100,000	5.4	1.6
600	0.5	0.2	150,000	6.6	1.9
700	0.5	0.2	200,000	7.6	2.1
750	0.5	0.2	250,000	8.4	2.3
800	0.5	0.2			

AQUEOUS AMMONIA

Alternative scenario spills of aqueous ammonia are going to be similar to worst-case scenario spills in that there will be a leak of some kind and the liquid will either spread across a diked area or spread out until its depth is only 1 cm (0.39 inch). The principal difference will be in the amount spilled.

The calculation of the rate of spillage is again performed using Bernoulli's formula see Appendix A4). The density of 30 percent aqueous ammonia is 57.33 lb/ft^3, so the equation becomes:

$$QR_L = 153 \times A_h \times (h)^{0.5} \tag{15}$$

where:

QR_L = rate of spillage of ammonia solution onto the ground (lbs/min), not the rate of evaporation
A_h = hole area (in^2)
h = static head

For example, for a ½-inch diameter opening with a static head h of 10 ft:

$$QR_L = 153 \times B \times (½×½)^2 \times \mathbf{/} 10 = 153 \times 3.142 \times 1/16 \times 3.16 = 95 \text{ lb/min}$$

This is the rate of spillage of the total solution of water plus ammonia as a liquid onto the ground.

If you know, and can document, how long it will take to stop the release, you should estimate the total quantity of solution spilled to the ground (QS) by multiplying the estimated rate of liquid spillage by the estimated duration of the release (in minutes). Then you can estimate the release rate to air (QR) as the evaporation rate of ammonia from the pool. For an undiked area (pool depth 1 cm):

$$QR = 0.025QS \tag{16}$$

For a diked pool (pool depth greater than 1 cm) of area A_p square feet:

$$QR = 0.046A_p \tag{17}$$

The maximum area of the pool that would be formed by the spilled liquid is 0.55QS. If you have a diked area that is larger than the maximum area, use the equation for an undiked area to estimate the release rate to air.

It is possible that you may estimate a rate of evaporation of ammonia from the pool that exceeds the spill rate of the liquid solution, particularly if the liquid spill rate is small and the spill of the liquid may last for a fairly long time. In such a case, under the assumptions used in this estimation method, no pool would be formed. Instead of the evaporation rate, in this case, you should use the liquid spill rate (QR_L) as the release rate to air.

You also can determine how far the pool will spread until the rate of spillage is matched by the rate of evaporation of ammonia. For aqueous ammonia at 77 °F (25 °C), the rate of evaporation is 0.046 A_p (from Equation 17).

The area that will cause the rate of evaporation to exactly balance the rate of spillage is given by:

$$A_p = QR/0.046 = 22QR_L \tag{18}$$

In the example given above, $QR_L = 95$ lb/min, so $A_p = 2,100$ ft². This value should be compared with the available diked area and the <u>smaller</u> of the two values chosen. Thus, if the diked area happens to be 50 ft x 50 ft = 2,500 ft², the area chosen for subsequent calculation is $A_p = 2,100$ ft² and QR = 95 lb/min. (If the diked area happened to be smaller — say 20 ft x 20 ft = 400 ft² — then the spilled ammonia would cover the diked area, and, using Equation 17, the rate of evaporation QR would be (0.046)(400) = 18 lb/min.)

To predict the distance to the toxic endpoint in typical weather conditions, take the value of QR calculated above and identify the closest value on Exhibit 4-21. Read off the corresponding distance. For the 95 lb/min case, the result is 0.2 mile for a rural site and 0.1 mile for an urban site. Alternatively, use Figure 4-8.

EXHIBIT 4-21
DISTANCES TO TOXIC ENDPOINT FOR AQUEOUS AMMONIA
D Stability, Wind Speed 3 Meters per Second

Release Rate (lbs/min)	Distance to Endpoint (miles)		Release Rate (lbs/min)	Distance to Endpoint (miles)	
	Rural	Urban		Rural	Urban
8	0.1	0.1	800	0.7	0.2
10	0.1		900	0.7	0.3
15	0.1		1,000	0.8	0.3
20	0.1		1,500	1.0	0.4
30	0.1		2,000	1.2	0.4
40	0.1		2,500	1.2	0.4
50	0.2	0.1	3,000	1.5	0.5
60	0.2	0.1	4,000	1.8	0.6
70	0.2	0.1	5,000	2.0	0.7
80	0.2	0.1	7,500	2.2	0.7
90	0.2	0.1	10,000	2.5	0.8
100	0.2	0.1	15,000	3.1	1.0
150	0.3	0.1	20,000	3.6	1.2
200	0.3	0.1	25,000	4.1	1.3
250	0.4	0.2	30,000	4.4	1.4
300	0.4	0.2	40,000	5.1	1.6
400	0.4	0.2	50,000	5.8	1.8
500	0.5	0.2	75,000	7.1	2.2
600	0.6	0.2	100,000	8.2	2.5
700	0.6	0.2	150,000	10	3.1
750	0.6	0.2	200,000	12	3.5

METHANE

Consider the case of methane released from a digester.   Assuming that the full contents of a digester were released over a few minutes (say 10 minutes), in the example given in Section 4.1, the release rate would be 105 lb/min (total quantity of methane in the digester, 1,053 lb). The LFL for methane is 33 mg/L. Conservatively taking digester gas/methane as a neutrally buoyant gas (it will actually rise from the ground), you need to use Exhibit 4-22 (for a rural site) or Exhibit 4-23 (for an urban site) to estimate the distance to the LFL. From Exhibit 4-22, the predicted distance for a release rate of 105 lb/min is 0.1 mile at a rural site and, from Exhibit 4-23, it is 0.1 mile at an urban site.

It is unlikely that a BLEVE would occur. They are not known to take place in low pressure containment such as that of a digester. A pool fire does not need to be considered, because the methane is not liquefied.

EXHIBIT 4-22
NEUTRALLY BUOYANT PLUME DISTANCES TO LOWER FLAMMABILITY LIMIT (LFL)
Rural Conditions, D Stability, Wind Speed 3.0 Meters per Second

Release Rate (lbs/min)	Distance to Endpoint (miles)	Release Rate (lbs/min)	Distance to Endpoint (miles)
0 - 1,980	0.1	108,900-128,700	1.0
1,980-7,260	0.2	128,700-148,500	1.1
7,260-17,490	0.3	148,500-171,600	1.2
17,490-28,380	0.4	171,600-191,400	1.3
28,380-42,900	0.5	191,400-224,400	1.4
42,900-56,100	0.6	224,400-270,600	1.6
56,100-72,600	0.7	270,600-320,100	1.8
72,600-89,100	0.8	320,100-363,000	2.0
89,100- 108,900	0.9	363,000-429,000	2.2

EXHIBIT 4-23
NEUTRALLY BUOYANT PLUME DISTANCES TO LOWER FLAMMABILITY LIMIT (LFL)
Urban Conditions, D Stability, Wind Speed 3.0 Meters per Second

Release Rate (lbs/min)	Distance to Endpoint (miles)	Release Rate (lbs/min)	Distance to Endpoint (miles)
0 - 4,950	0.1	240,900-303,600	0.8
4,950-23,430	0.2	303,600-363,000	0.9
23,430-49,500	0.3	363,000-462,000	1.0
49,500-85,800	0.4	462,000-594,000	1.2
85,800-132,000	0.5	594,000-858,000	1.4
132,000-181,500	0.6	858,000-1,023,000	1.6
181,500-240,900	0.7	1,023,000-1,254,000	1.8

4.3   BUILDINGS

In many WWTPs, chlorine and sulfur dioxide cylinders or other vessels are kept indoors. Unless your cylinders are delivered directly into the building (i.e., they are not unloaded outdoors and moved inside later), you should not consider buildings in your worst-case scenario, even though they are passive mitigation systems, because there will be some time when the vessels are outdoors. If your cylinders are delivered indoors or if your largest vessel is indoors, you may want to analyze the mitigating effects of the building when you do your worst-case analysis. You may also want to consider alternative scenarios that consider buildings as mitigation systems. Some buildings are strong, leak-tight buildings that are designed to contain the release of the contents of a one-ton cylinder or other vessel. Some of them contain scrubbers that activate upon release of chlorine or sulfur dioxide; if these scrubbers function as designed, they can ensure that any release to the external atmosphere would be small. (Scrubbers are active mitigation features that cannot be considered to work for a worst-case scenario.) At the other end of the spectrum, some buildings are intended to do no more than keep the rain off.

MITIGATION OF RELEASES OF ANHYDROUS AMMONIA, CHLORINE, OR SULFUR DIOXIDE INTO BUILDINGS

EPA's *RMP Offsite Consequence Analysis Guidance* provides a simple building release-rate-multiplicative factor of 55 percent for toxic gases in both worst-case and alternative scenarios (i.e., the predicted rate of release is 55 percent of that for the same accident if it should occur outdoors).

Example: Assume that there is a liquid chlorine release through a 5/16-inch opening as described in the discussion of chlorine alternative scenarios (see Exhibit 4-12). This release takes place indoors and, per the discussion above, is reduced to 55 percent of the release rate of 240 lb/min, i.e., to . 130 lb/min. From Exhibit 4-11, the predicted distance to the toxic endpoint is . 0.6 mile for a rural site and . 0.2 mile for an urban site, compared to 0.7 mile (rural) and 0.3 mile (urban) for an outdoor release.

The *RMP Offsite Consequence Analysis Guidance* also provides factors for toxic liquids of 10 percent for worst-case scenarios and 5 percent for alternative scenarios. These factors may be used for releases of aqueous ammonia that take place inside buildings.

The following discussion provides a more sophisticated approach for considering effects of building mitigation for worst-case (if appropriate) and alternative scenarios involving release of gases and mixtures of gases and entrained liquid. Analysis of release scenarios inside buildings involves consideration of the structure of the building, liquid rain-out, and release containment issues. The procedure addressing these issues which is recommended for developing release rate estimates for both worst-case (if appropriate) and alternative scenarios is presented in Figure 4-9.

The release into the building is assumed to occur over a 10-minute period. For the worst-case scenario, the quantity released into the building equals the total quantity in the largest vessel or pipeline. For alternative scenarios, you must estimate the total quantity of ammonia, chlorine, or sulfur dioxide released from the equipment over a 10-minute period. This 10-minute assumption is made to keep this guidance simple.

Calculations of the likely rise in pressure show that, for a release distributed over 10 minutes, building failure is unlikely to occur unless you have a very large vessel in a very small room. However, if the ratio of room volume to quantity in the vessel is < $0.1 \, ft^3/lb$ for ammonia and < $0.05 \, ft^3/lb$ for chlorine or sulfur dioxide, you should look at the possibility that the room will fail by windows blowing out or doors blowing open.

If the release is indoors directed towards a door or window that is potentially open, the release rate to the outside is the total quantity, uniformly distributed over 10 minutes. If the release is indoors and not directed towards a door or window, mitigation of the release by scrubbing, rain-out, or ventilation dilution may occur. If there is a scrubber, the release of material to the environment may be low. If there is no scrubber, the ventilation rate N_v, expressed as room volumes exchanged per hour, is identified, and the room volume per unit quantity of either ammonia, chlorine, or sulfur dioxide vapor released to the room (1) and the quantity airborne in the room (Q_a) are calculated for either a vapor or a vapor/liquid release.

For vapor releases, the amount of vapor released into the room is clearly Q, so 1 = V/Q. For a flashing liquid release, . 20 percent of the release typically flashes to vapor, so 1 = V/(0.2Q). The quantity airborne in the room is the total quantity released from the equipment to the room in 10 minutes for vapor releases and four-tenths of the total quantity released from the equipment to the room in 10 minutes for vapor/liquid releases. The basis for this four-tenths assumption is that, in a room, a flashing liquid jet will encounter obstacles that will cause 60 percent of the release to collect as a relatively slowly evaporating pool on the ground. The release over the initial ten minutes leads to predictions of higher concentrations downwind than does the slowly evaporating pool; therefore, you can consider only the release rate of the airborne material (0.4Q/10) and ignore the evaporating pool in estimating the distance to the toxic endpoint.

Given the values of N_v and 1, the building mitigation factor (FR_{10}) is identified for 10-minute releases of ammonia in Exhibit 4-24, and for 10-minute releases of either chlorine or sulfur dioxide in Exhibit 4-25, respectively. The release rate to the environment is the total quantity airborne in the room, reduced by the building mitigation factor, distributed uniformly over 10 minutes.

Example: A 25-ton (50,000 lb) chlorine storage vessel is in a room of dimensions 40 feet x 40 feet x 30 feet = 48,000 ft^3. There is a worst-case release, so that the 50,000 lb is released into the building over a period of 10 minutes. The release is not adjacent to a potentially open door or window. Because it is a worst-case scenario, the scrubber (if there is one) is not operating. The ventilation rate N_v =

4. The release is a mixture of vapor and liquid droplets, so that $1 = V/(0.2Q) = 48,000/10,000 = 4.8$ ft^3/lb, and the airborne quantity $Q_a = 0.4Q = 20,000$ lb. From Exhibit 4-24, with $N_v = 4$ and $1 = 4.8$ (the closest entries on Exhibit 4-25 are $N_v = 5$ and $1 = 4.0$), $FR_{10} = 0.46$.

Therefore, the predicted worst-case scenario release rate from the building is:

$$0.46 \times ((0.4 \times 50,000)/10) = 920 \text{ lb/min}$$

Compare this value with 5,000 lb/min from an open-air release. From Exhibit 4-4, the predicted distance for a 920 lb/min release at a rural site is 6.3 miles and, at an urban site, is 2.9 miles. By comparison, the 5,000 lb/min release would lead to corresponding distances of 15 miles and 7 miles, respectively.

Example: Take a chlorine alternative scenario for a flashing liquid release through a 1/4-inch hole (see Section 4.2). Exhibit 4-13 shows a release rate of 150 lbs/min for this release. Assume this release takes place in a building with no scrubber for 10 minutes at a release rate of 150 lb/min for a total release of 1,500 lb. Assume that the building has dimensions of 50 feet x 25 feet x 20 feet = 25,000 ft^3. The release is a flashing liquid and, therefore, consists of a mixture of vapor and liquid. Q_a, the quantity that becomes airborne, is $(0.4)(1,500) = 600$ lb. The quantity of vapor is $(0.2)(1,500) = 300$ lb. Then $1 = 25,000/300 = 83$. 80. You will have to determine N_v from the characteristics of your building. For this example, assume that the building is being ventilated with $N_v = 5$. From Exhibit 4-25, $FR_{10} = 0.32$, so that the rate of release to the external atmosphere is $(0.1)(0.32)(600) = 19$ lb/min. From Exhibit 4-11, the predicted distance to the endpoint is 0.2 mile for a rural site and 0.1 mile for an urban site. For the original release rate of 150 lb/min, the distances to the endpoint are 0.6 mile for a rural site and 0.2 mile for an urban site.

EXHIBIT 4-24
TEN-MINUTE BUILDING RELEASE ATTENUATION FACTORS FOR PROLONGED
RELEASES OF ANHYDROUS AMMONIA

2 (ft³/lb)	N_v (hr⁻¹)	FR_{10} (dim)	2 (ft³/lb)	N_v (hr⁻¹)	FR_{10} (dim)
160	0	0.07	8.0	0	0.67
	1	0.08		1	0.67
	5	0.32		5	0.67
	10	0.51		10	0.67
	20	0.71		20	0.71
	30	0.80		30	0.80
	40	0.85		40	0.85
80	0	0.13	4.0	0	0.83
	1	0.13		1	0.83
	5	0.32		5	0.83
	10	0.51		10	0.83
	20	0.71		20	0.83
	30	0.80		30	0.83
	40	0.85		40	0.85
32	0	0.29	0.80	0	0.97
	1	0.29		1	0.97
	5	0.32		5	0.97
	10	0.51		10	0.97
	20	0.71		20	0.97
	30	0.80		30	0.97
	40	0.85		40	0.97
16	0	0.47	0.32	0	0.99
	1	0.47		1	0.99
	5	0.47		5	0.99
	10	0.51		10	0.99
	20	0.71		20	0.99
	30	0.80		30	0.99
	40	0.85		40	0.99

EXHIBIT 4-25
TEN-MINUTE BUILDING RELEASE ATTENUATION FACTORS FOR PROLONGED
RELEASES OF CHLORINE AND SULFUR DIOXIDE

$\frac{2}{(ft^3/lb)}$	N_v (hr^{-1})	FR_{10} (dim)	$\frac{2}{(ft^3/lb)}$	N_v (hr^{-1})	FR_{10} (dim)
160	0	0.02	8.05	0	0.28
	1	0.08		1	0.28
	5	0.32		5	0.32
	10	0.51		10	0.51
	20	0.71		20	0.71
	30	0.80		30	0.80
	40	0.85		40	0.85
80	0	0.03	4.0	0	0.46
	1	0.08		1	0.46
	5	0.32		5	0.46
	10	0.51		10	0.51
	20	0.71		20	0.71
	30	0.80		30	0.80
	40	0.85		40	0.85
32	0	0.08	0.80	0	0.85
	1	0.08		1	0.86
	5	0.32		5	0.86
	10	0.51		10	0.86
	20	0.71		20	0.86
	30	0.80		30	0.86
	40	0.85		40	0.86
16	0	0.15	0.32	0	0.94
	1	0.15		1	0.94
	5	0.32		5	0.94
	10	0.51		10	0.94
	20	0.71		20	0.94
	30	0.80		30	0.94
	40	0.85		40	0.94

4.4   ESTIMATING OFFSITE RECEPTORS

The rule requires that you estimate in the RMP residential populations within the circle defined by the endpoint for your worst-case and alternative release scenarios (i.e., the center of the circle is the point of release and the radius is the distance to the endpoint). In addition, you must report in the RMP whether certain types of public receptors and environmental receptors are within the circles.

RESIDENTIAL POPULATIONS

To estimate residential populations, you may use the most recent Census data or any other source of data that you believe is more accurate. You are not required to update Census data or conduct any surveys to develop your estimates. Census data are available in public libraries and in the LandView system, which is available on CD-ROM (see box below). The rule requires that you estimate populations to two-significant digits. For example, if there are 1,260 people within the circle, you may report 1,300 people. If the number of people is between 10 and 100, estimate to the nearest 10. If the number of people is less than 10, provide the actual number. Census data are presented by Census tract. If your circle covers only a portion of the tract, you should develop an estimate for that portion. The easiest way to do this is to determine the population density per square mile (total population of the Census tract divided by the number of square miles in the tract) and apply that density figure to the number of square miles within your circle. Because there is likely to be considerable variation in actual densities within a Census tract, this number will be approximate. The rule, however, does not require you to correct the number.

OTHER PUBLIC RECEPTORS

Other public receptors must be noted in the RMP (see the discussion of public receptors in Chapter 2). If there are any schools, residences, hospitals, prisons, public recreational areas or arenas, or commercial or industrial areas within the circle, you must report that. You are not required to identify the specific public receptors; you must simply check off the categories of such areas within the circle. Most receptors can be identified from local street maps.

ENVIRONMENTAL RECEPTORS

Environmental receptors are defined as natural areas such as national or state parks, forests, or monuments; officially designated wildlife sanctuaries, preserves, refuges, or areas; and Federal wilderness areas. Only environmental receptors that can be identified on local U.S. Geological Survey (USGS) maps (see box below) need to be considered. You are not required to locate each of these specifically. You are only required to check off in the RMP which specific types of areas are within the circle. If any part of one of these receptors is within your circle, you must note that in the RMP.

Important: The rule does not require you to assess the likelihood, type, or severity of potential impacts on either public or environmental receptors. Identifying them as within the circle simply indicates that they could be adversely affected by the release.

Besides the results you are required to report in the RMP, you may want to consider submitting to EPA or providing your local community with a map showing the distances to the endpoint. Figure 4-10 is one suggested example of how the consequences of worst-case and alternative scenarios might be presented. It is a simplified map that shows the radius to which the vapor cloud might extend, given the worst-case release in worst-case weather conditions (the owner or operator should use a real map of the area surrounding the site). Organizations that have prepared Risk Management Programs and Plans have used this form of presentation (for example, in the Kanawha Valley or in Tampa Bay).

HOW TO OBTAIN CENSUS DATA AND LANDVIEW®

Census data can be found in publications of the Bureau of the Census, available in public libraries, including *County and City Data Book*.

LandView ®III is a desktop mapping system that includes database extracts from EPA, the Bureau of the Census, the U.S. Geological Survey, the Nuclear Regulatory Commission, the Department of Transportation, and the Federal Emergency Management Agency. These databases are presented in a geographic context on maps that show jurisdictional boundaries, detailed networks of roads, rivers, and railroads, census block group and tract polygons, schools, hospitals, churches, cemeteries, airports, dams, and other landmark features.

CD-ROM for IBM-compatible PCS
CD-TGR95-LV3-KIT $99 per disc (by region) or $549 for 11 disc set

U.S. Department of Commerce
Bureau of the Census
P.O. Box 277943
Atlanta, GA 30384-7943
Phone: 301-457-4100 (Customer Services—orders)
Fax: (888) 249-7295 (toll-free)
Fax: (301) 457-3842 (local)
Phone: (301) 457-1128 (Geography Staff—content)
http://www.census.gov/ftp/pub/geo/www/tiger/

Further information on LandView and other sources of Census data is available at the Bureau of the Census web site at www.census.gov.

HOW TO OBTAIN USGS MAPS

The production of digital cartographic data and graphic maps comprises the largest component of the USGS National Mapping Program. The USGS's most familiar product is the 1:24,000-scale Topographic Quadrangle Map. This is the primary scale of data produced, and depicts greater detail for a smaller area than intermediate-scale (1:50,000 and 1:100,000) and small-scale (1:250,000, 1:2,000,000 or smaller) products, which show selectively less detail for larger areas.

U.S. Geological Survey
508 National Center
12201 Sunrise Valley Drive
Reston, VA 20192
www.mapping.usgs.gov/

To order USGS maps by fax, select, print, and complete one of the online forms and fax to 303-202-4693. A list of commercial dealers also is available at www.mapping.usgs.gov/esic/usimage/dealers.html/. For more information or ordering assistance, call 1-800-HELP-MAP, or write:

USGS Information Services
Box 25286
Denver, CO 80225

For additional information, contact any USGS Earth Science Information Center or call 1-800-USA-MAPS.

4.5   DOCUMENTATION

You need to maintain onsite the following records on the offsite consequence analyses:

For the worst-case scenario, a description of the vessel or pipeline selected as worst-case, assumptions and parameters used and the rationale for selection; assumptions include use of any administrative controls and any passive mitigation systems that you assumed to limit the quantity that could be released.

For alternative release scenarios, a description of the scenarios identified, assumptions and parameters used and the rationale for the selection of specific scenarios; assumptions include use of any administrative controls and any mitigation that were assumed to limit the quantity that could be released. Documentation includes the effect of the controls and mitigation on the release quantity and rate. You can reference this guidance if you use any of the "canned" scenarios described herein.

Other data that you should maintain includes:

    g Documentation of estimated quantity released, release rate and duration of release.

    g Methodology used to determine distance to endpoints (it will be sufficient to reference this guidance if you used it for that purpose).

   g Data used to identify potentially affected population and environmental receptors.

4.6 SYMBOLS FOR CHAPTER 4

A_h area of hole in pipe, in^2

A_p area of pool or diked area, ft^2

C_p specific heat of gas at constant pressure, Btu/lb/°F

C_{pl} specific heat of liquid, Btu/lb/°F

C_v specific heat of gas at constant volume, Btu/lb/°F

D distance to toxic or explosive endpoint, mi

d_h diameter of hole in pipe or tank, ft^2

F frictional loss factor in equation for calculating the rate of discharge of liquid chlorine, sulfur dioxide, or ammonia from a pipe, dimensionless

g acceleration due to gravity, $32ft/s^2$

h static head in a vessel, ft

h_L latent heat of vaporization of a liquid, Btu/lb

H maximum head space in a digester, ft

L length of pipework, ft

N_v ventilation rate, room volumes/hr

p_g gauge pressure, pounds per square inch gauge (psig)

p_a absolute pressure, pounds per square inch absolute (psia)

Q mass released, lb

Q_a mass that remains airborne for the case of a release of chlorine, sulfur dioxide, or anhydrous ammonia into a building, lb

QR rate of release, lb/min

QS mass spilled into a pool, lb

r radius of a digester, ft

$R_{vp}(T)$ ratio of vapor pressure of ammonia over a pool of aqueous ammonia at temperature T to the vapor pressure at 25 °C, dimensionless

T temperature, °F or °C, depending on context

V volume of a digester in a room, ft^3

v_{lg} difference in specific volume between gas and liquid, ft^3/lb

X percent of methane in digester gas, dimensionless

(ratio of specific heats, C_p/C_v, dimensionless

D_L density of liquid, lb/ft^3

D_m density of methane in digester gas, lb/ft^3

D_o density of gas at pressure p_a, lb/ft^3

2 room volume per unit mass of chlorine, sulfur dioxide, or anhydrous ammonia, ft^3/lb

. approximately equal to

– approximately

Figure 4-1 Worst-Case Scenario--Predicted Distances to Toxic Endpoint For Chlorine @ Atmospheric Stability Class F with Windspeed 1.5 m/s
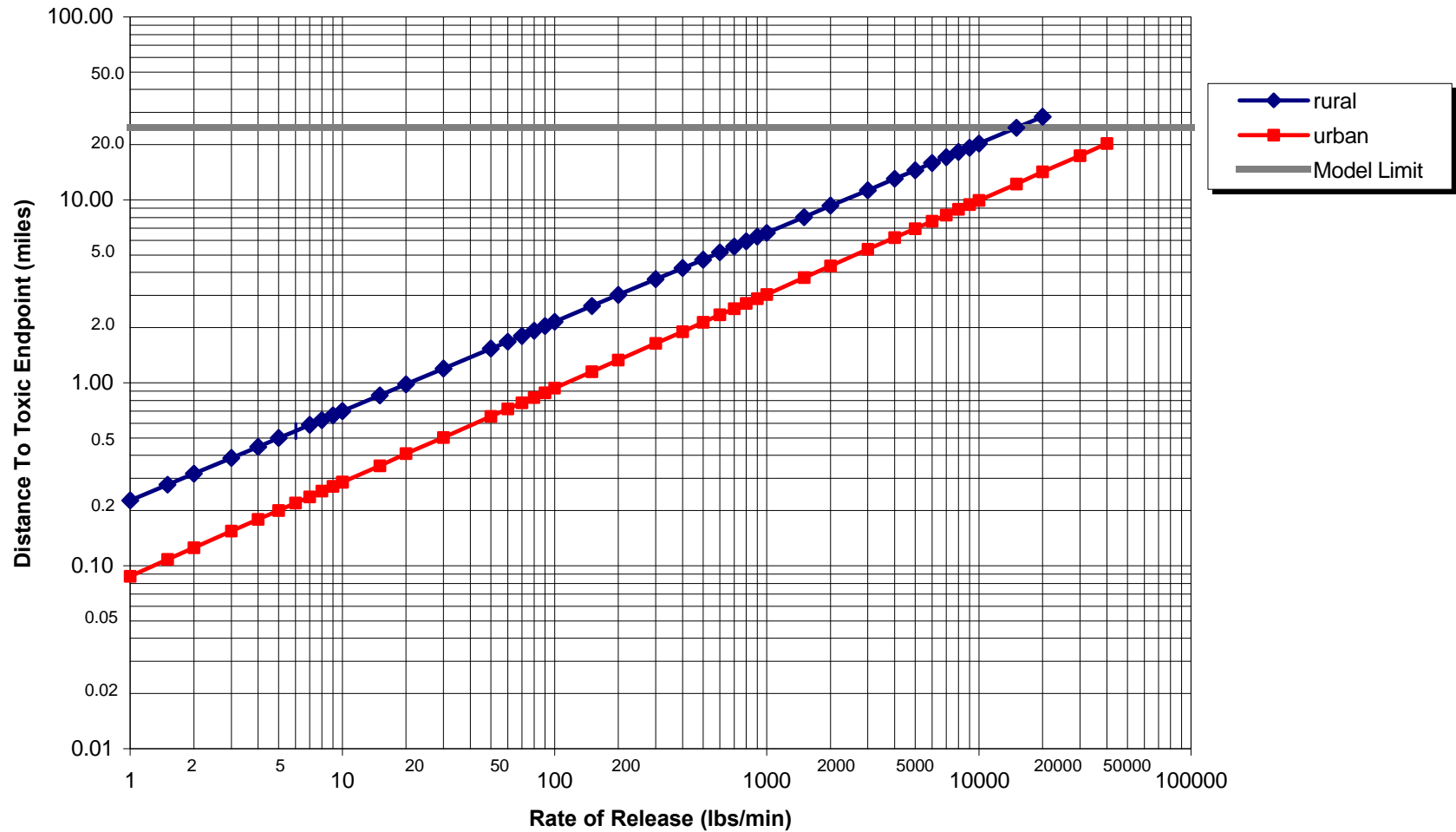
Figure 4-2 Worst-Case Scenario - Predicted Distances to Toxic Endpoint For SO2 @ Atmospheric Sability Class F with Windspeed 1.5 m/s
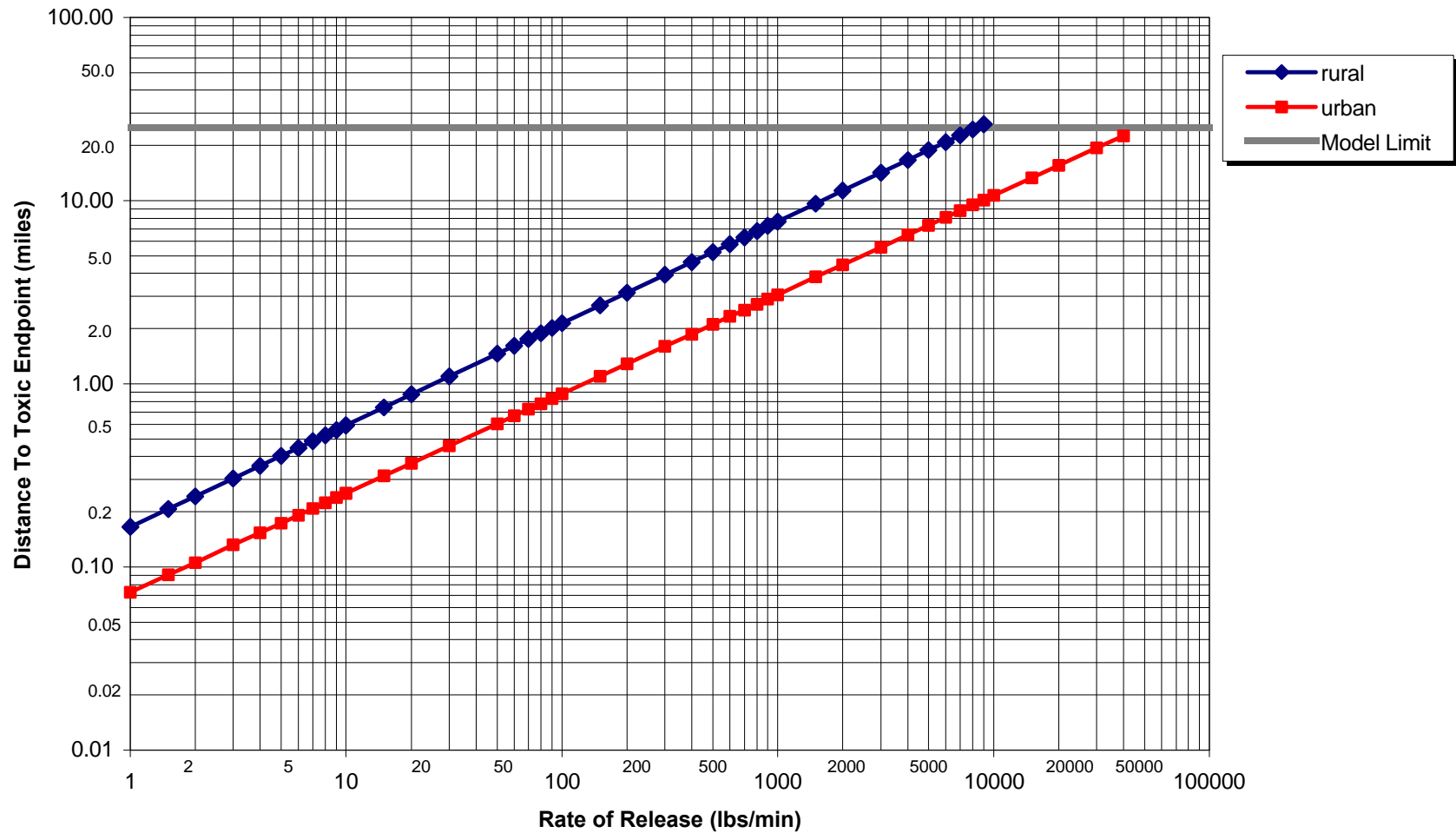
Figure 4-3 Worst-Case Scenario - Predicted Distances to Toxic Endpoint
Anhydrous Ammonia @ Atmospheric Stability Class F with Windspeed 1.5 m/s
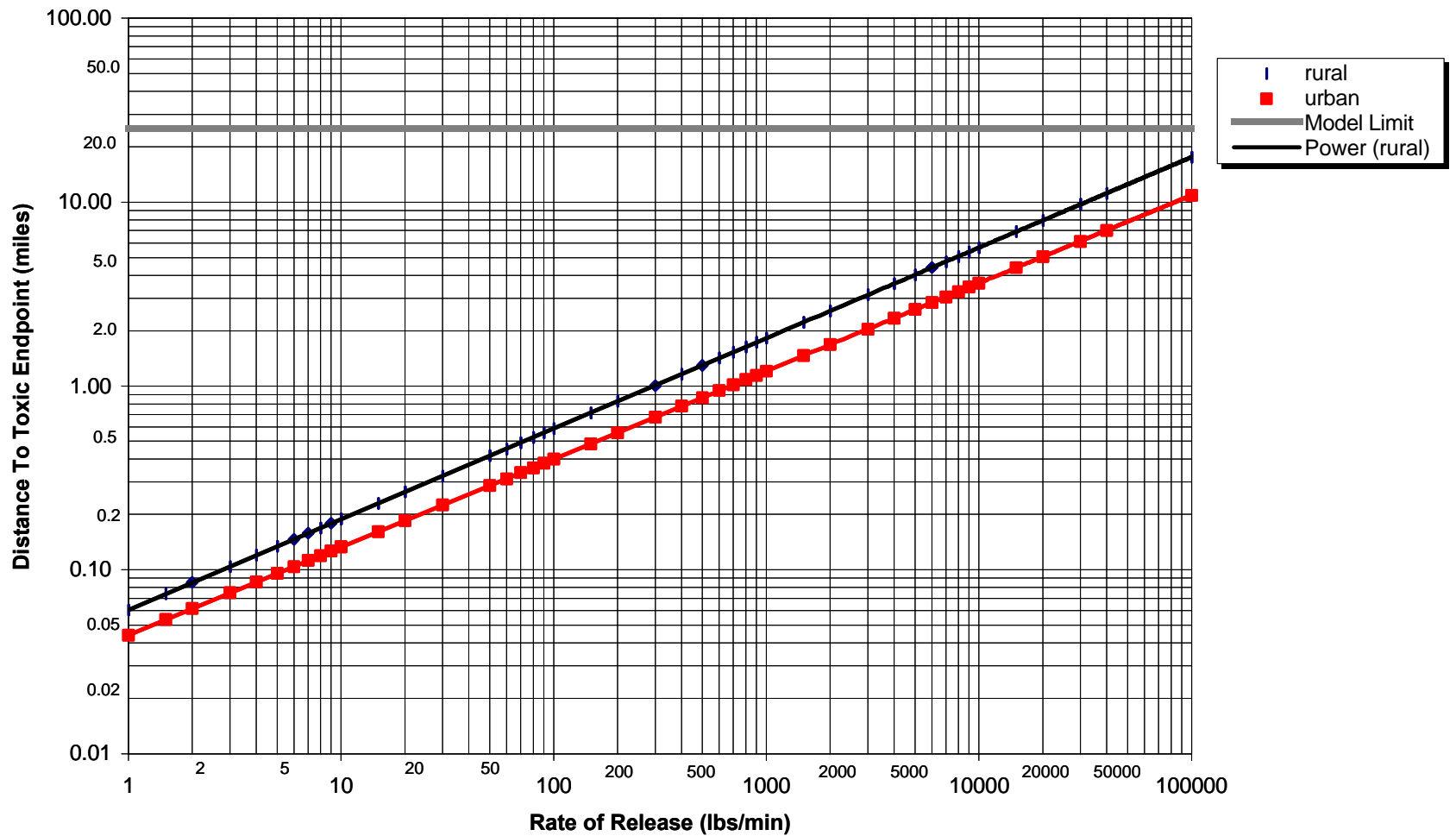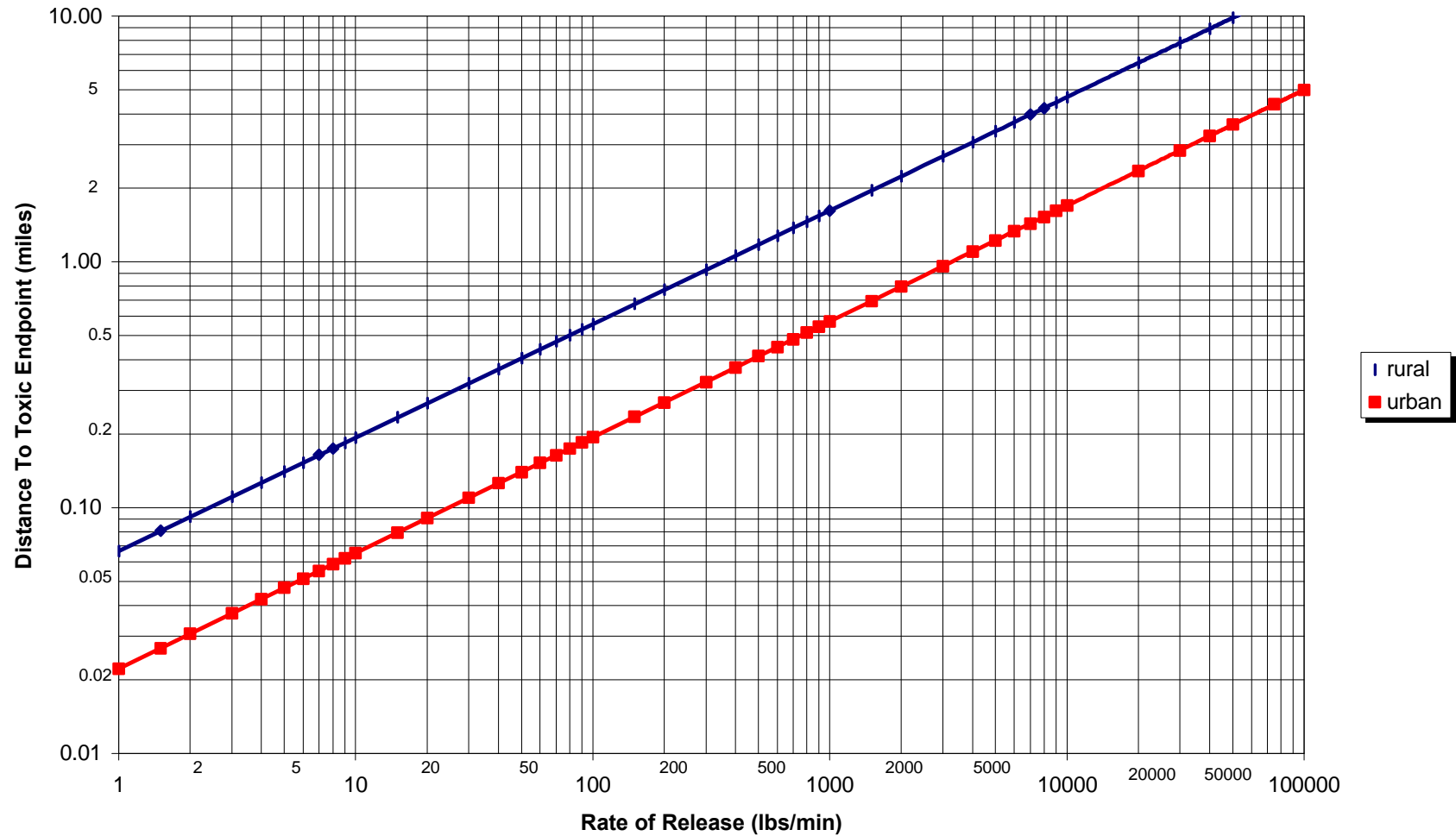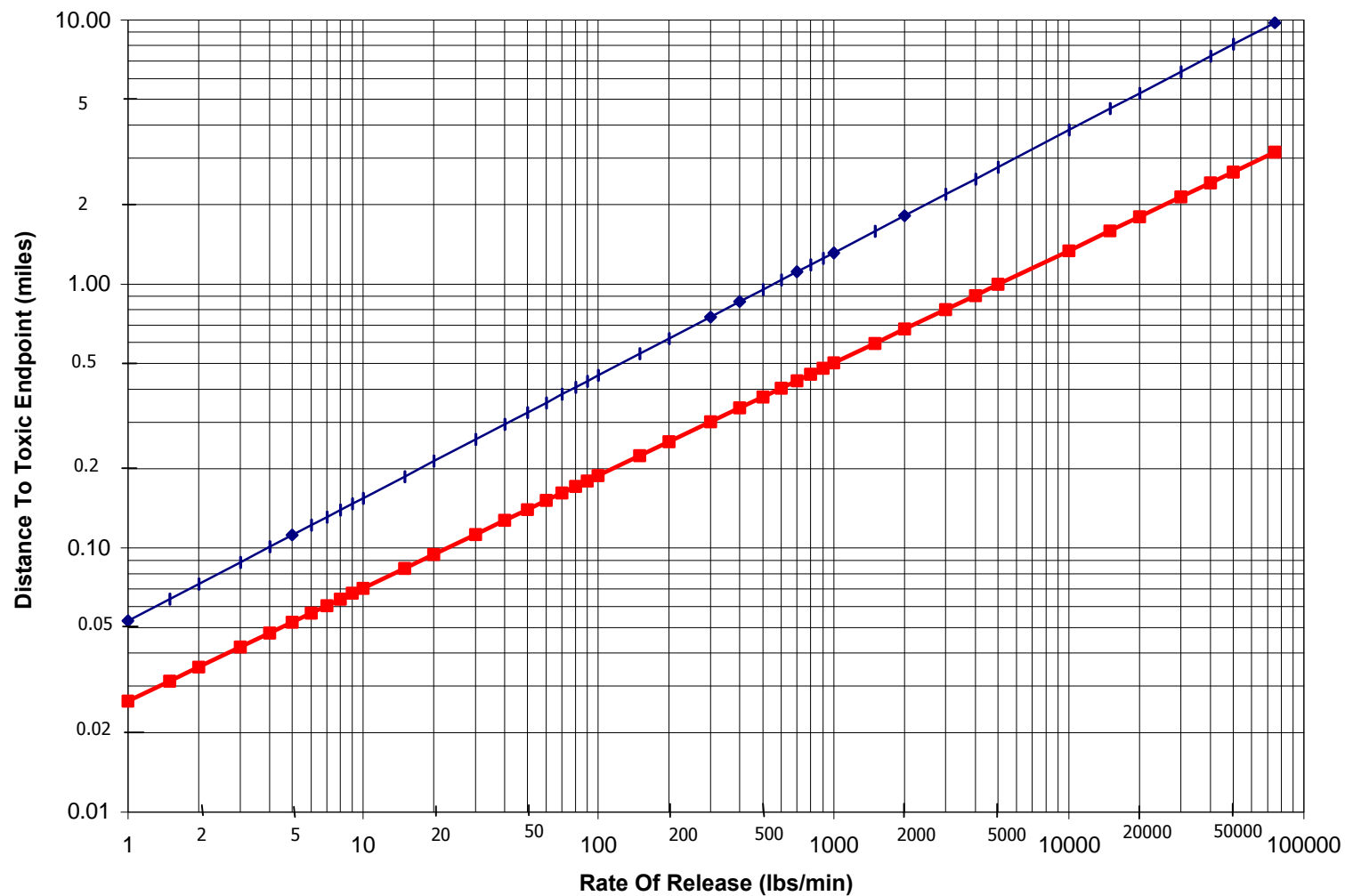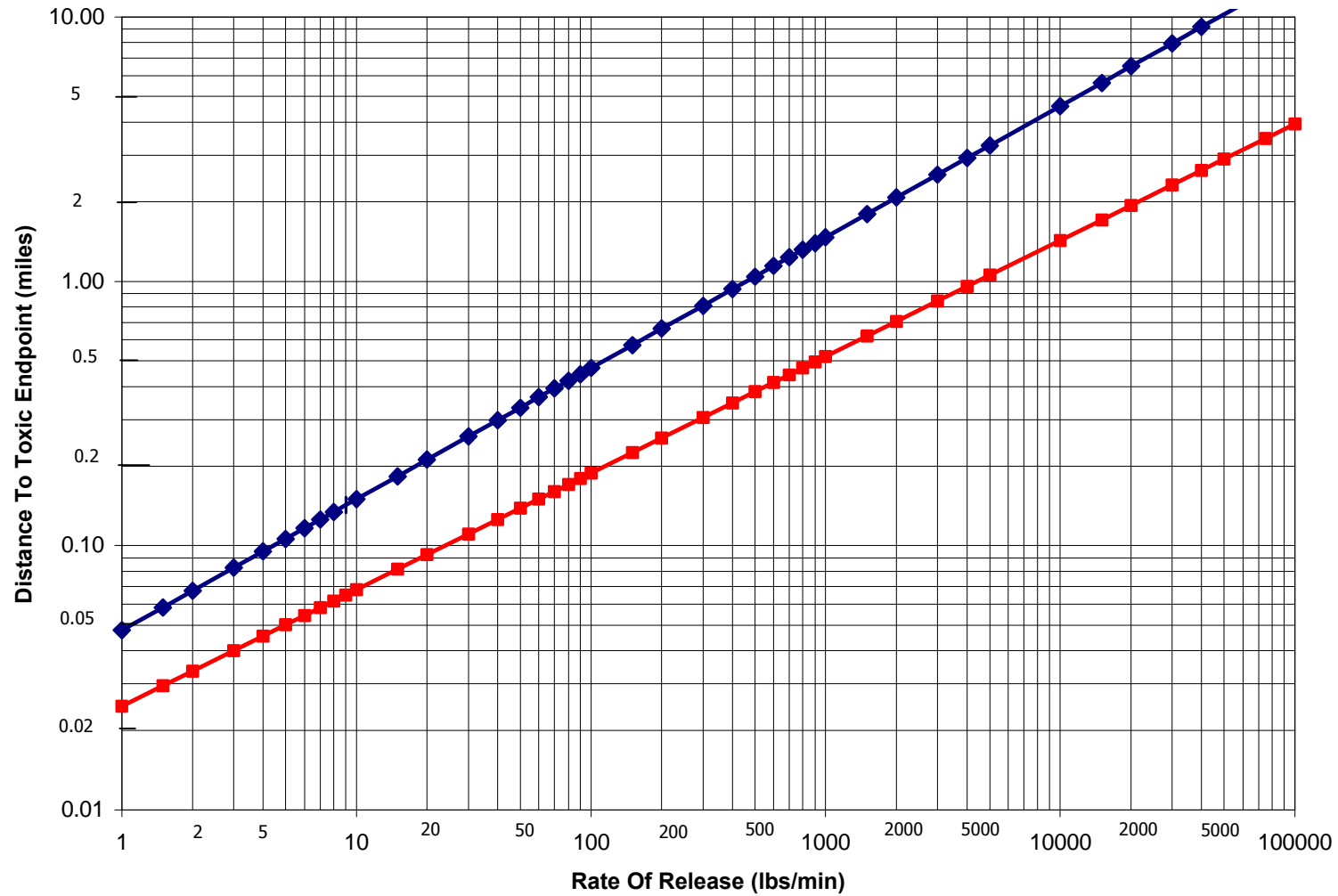
Figure 4-4 Worst-Case Scenario - Predicted Distances To Toxic Endpoint Aqueous Ammonia @ Atmospheric Stability Class F with Windspeed 1.5 m/s
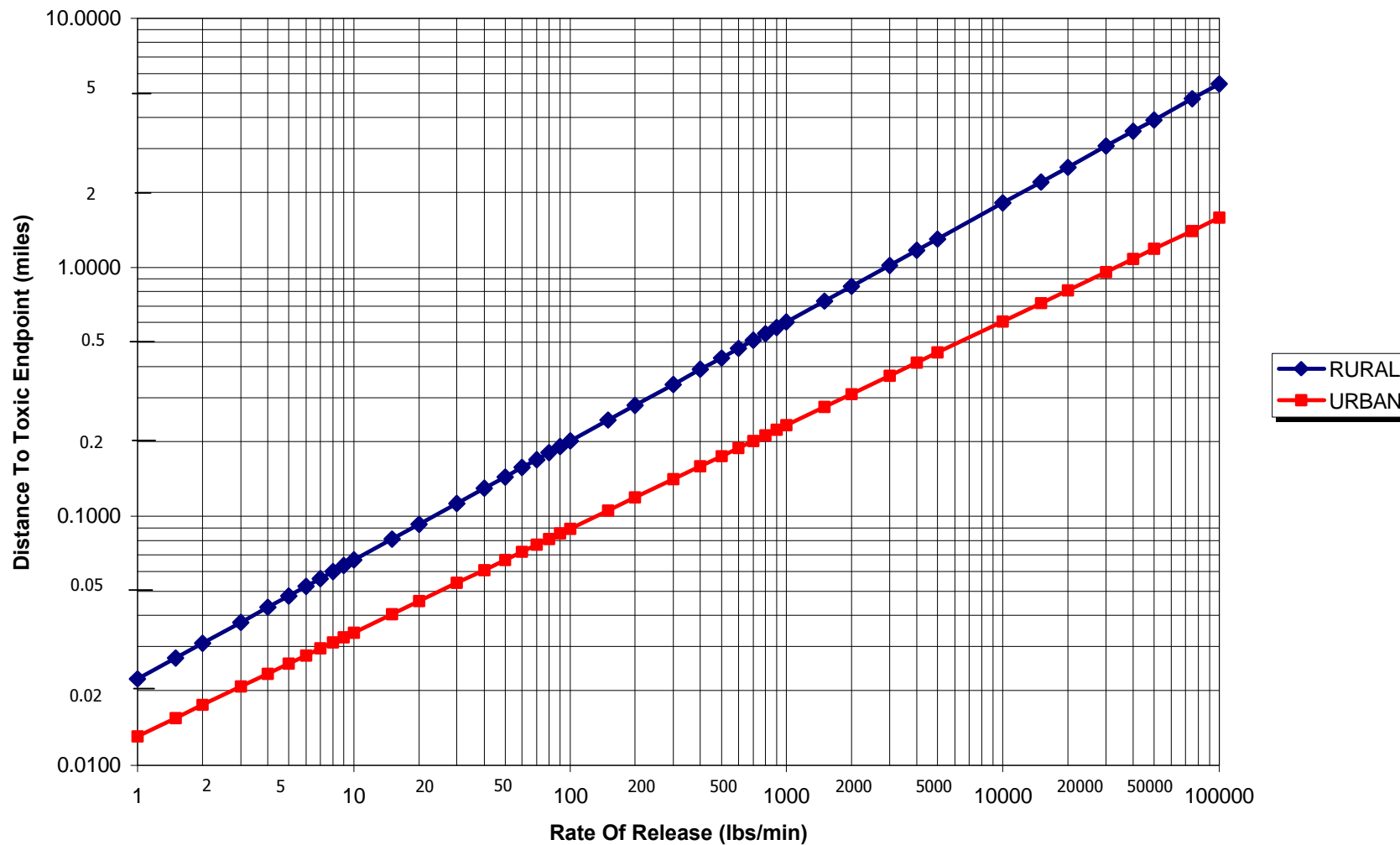
Figure 4-5 Alternative Case Scenario - Predicted Distances To Toxic Endpoint For Chlorine @ Atmospheric Stability Class D with Windspeed 1.5 m/s

Figure 4-6 Alternative Case Scenario - Predicted Distances To Toxic Endpoint For SO2 @ Atmospheric Stability Class D with Windspeed 1.5 m/s

Figure 4-7 Alternative Case Scenario - Predicted Distances To Toxic Endpoint For Anhydrous Ammonia @ Atmospheric Stability Class D with Windspeed 1.5 m/s
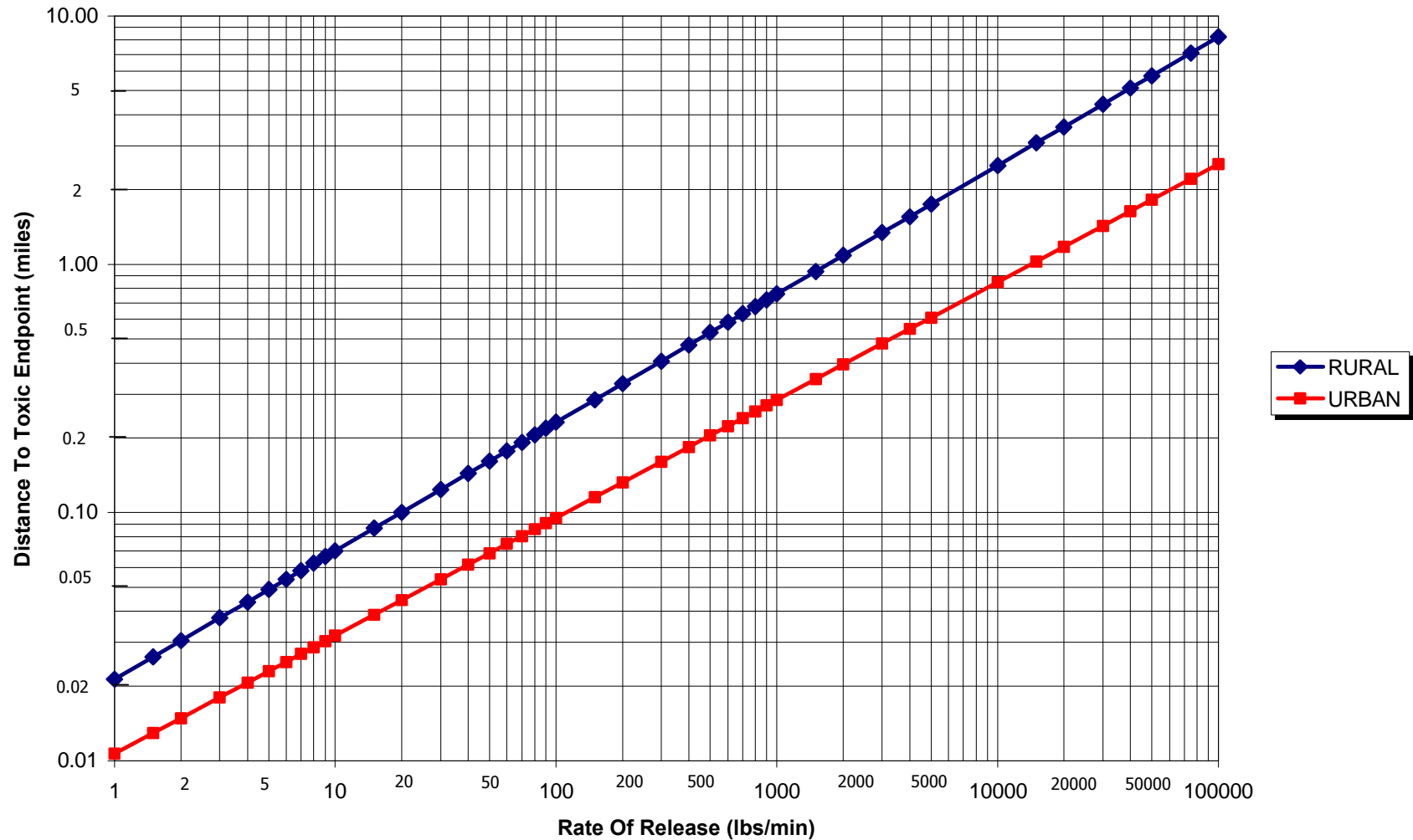
Figure 4-8 Alternative Case Scenario - Predicted Distances To Toxic Endpoint For Aqueous Ammonia @ Atmospheric Stability Class D with Windspeed 1.5 m/s

Calculate Total Release M(lb)

Indoors or Outside?

Outdoors → Release Rate 0.1Mlb/min

Indoors ↓

Adjacent to door or window?

Yes → Release Rate 0.1Mlb/min

No ↓

Scrubber?

Yes → Minimal Release to Environment

No ↓

Choose N_v (hr^{-1})

Release Entirely Vapor?

Yes → Calculate $\grave{e} = V/M$ → Airborne Mass $M_a = M$

No → Calculate $\grave{e} = V/(0.2M)$ → Airborne Mass $M_a = 0.4M$

Calculate FR_{10} Table 4-17 or 4-18

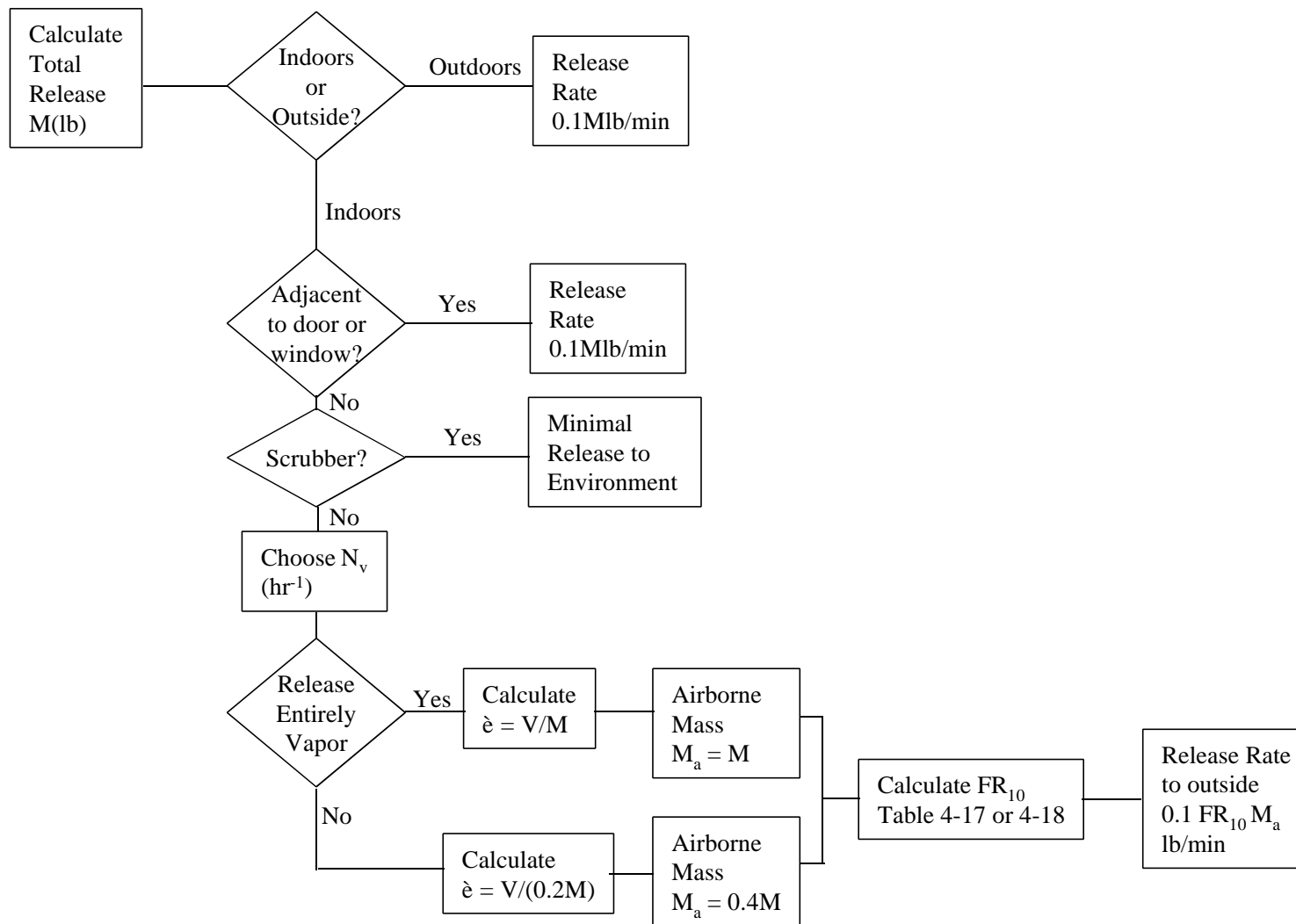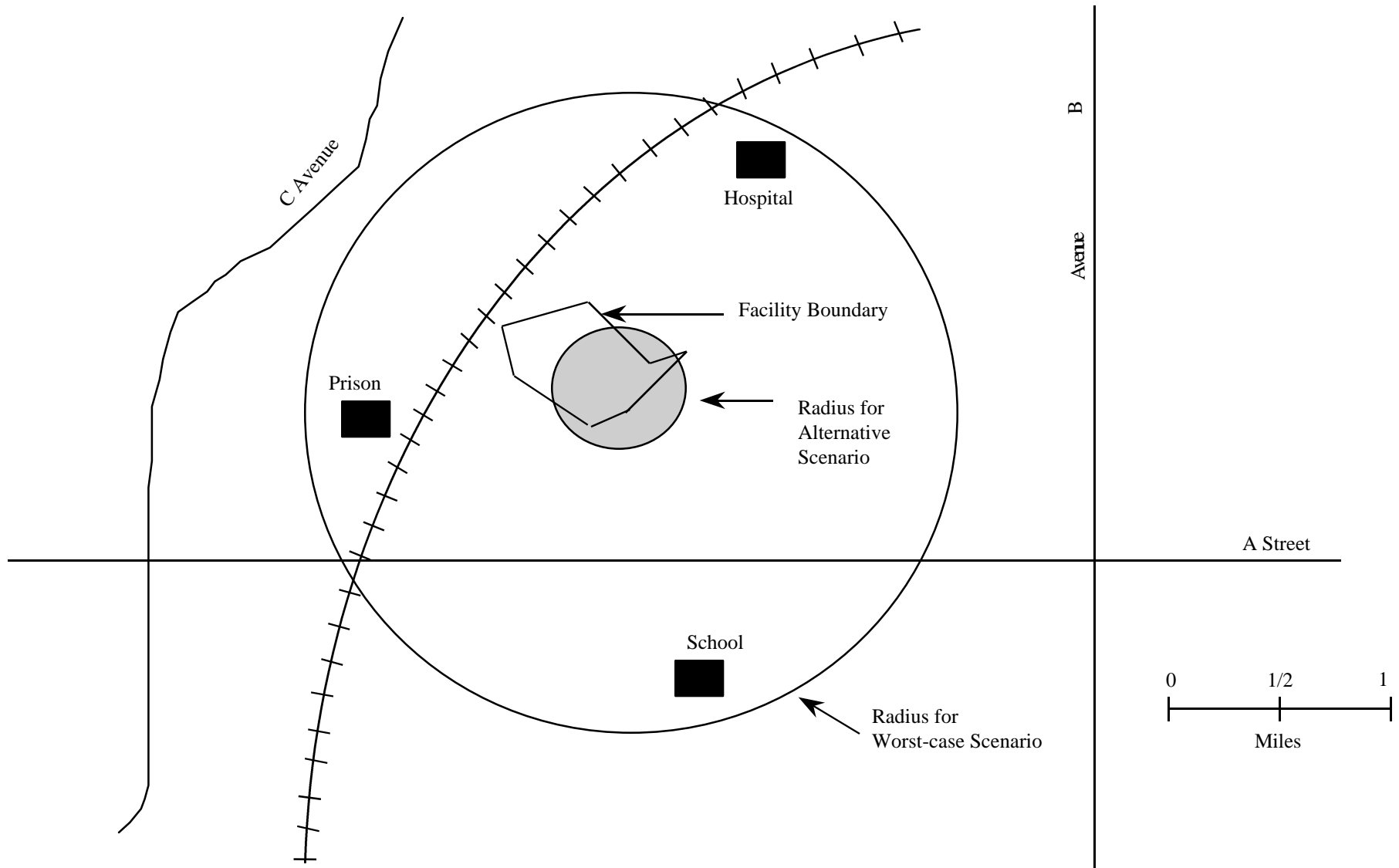Release Rate to outside $0.1\ FR_{10}\ M_a$ lb/min

Figure 4-9. Guidance on Effectiveness of Building Mitigation for Alternative Scenarios

Figure 4-10 Simplified Presentation of Worst-Case and Alternative Scenario on a Local Map

C Avenue

B Avenue

Hospital

Facility Boundary

Prison

Radius for
Alternative
Scenario

A Street

School

Radius for
Worst-case Scenario

0   1/2   1

Miles

APPENDIX 4A
EQUATIONS

AMMONIA PARTIAL PRESSURE

The ratio $R_{vp}(T)$ of the partial pressure of ammonia at temperature T ^{o}C to the partial pressure at 25 ^{o}C is given by the empirical formula:

$$R_{vp}(T) = \exp[10.438 - 717.4/(T + 273.4) - 2132.5/(T + 240.25)]$$

DENSITY OF METHANE IN DIGESTER

$$D_m = (X/100)(0.0409)(537/(460+T)) = 0.22 \ X/(460+T)$$

where 0.0409 lb/ft^3 is the density of pure methane at 77 ^{o}F (25 ^{o}C) and the factor 537/(460+T) represents how the density changes with temperature, assuming that methane obeys the perfect gas law. The effect of the small operating pressure in compressing the gas has been ignored.

ALTERNATIVE RELEASE EQUATIONS

Bernoulli's Formula

The rate of release of a liquid through an hole is given by Bernoulli's formula for predicting the rate of release QR (lb/min) of liquid from a vessel:

$$m = A_h \ C_d (D_l[2g \ D_l(H_L - H_h) + 2(P_0 - P_a)])^2 \tag{A-1}$$

where:
m	=	Discharge rate (kilograms per second)
A_h	=	Opening area (square meters)
C_d	=	Discharge coefficient (unitless)
g	=	Gravitational constant (9.8 meters per second squared)
D_l	=	Liquid density (kilograms per cubic meter)
P_0	=	Storage pressure (Pascals)
P_a	=	Ambient pressure (Pascals)
H_L	=	Liquid height above bottom of container (meters)
H_h	=	Height of opening (meters)

To create the equations in the text, this equation was converted to English units.

Gases Liquefied under Pressure

For gases liquefied under high pressure, the term containing the liquid height in Equation A-1 can be neglected. The equation for the release rate for gases liquefied under pressure becomes:

$$QR = 32.07 \times A_h \times D_l \times (P_g / D_l)^{0.5} \tag{A-2}$$

To derive the chemical specific factors presented in the text for gases liquefied under their vapor pressure at 25 °C, the following data were substituted into Equation A-3:

Liquefied Gas	Liquid Density (D_L), lbs/ft^3	Tank Vapor Pressure (P_g), psig
Chlorine	97.5	98.5
Sulfur dioxide	91.3	43.3
Ammonia	42.5	130

Liquid at Ambient Pressure

For liquids stored at ambient pressure, the difference between storage pressure and ambient pressure is zero, and the pressure term drops out of Equation A-1 above. The equation can be rewritten and converted to English units as follows:

$$QR = 132.2 \times A_h \times 6.4516 \times 10^{-4} \times (h)^{0.5} \times 0.5521 \times 0.8 \times (2 \times 9.8)^{0.5} \times D_L \times 16.018 \qquad \text{(A-3)}$$

where:

QR	=	Release rate (pounds per minute)
132.2	=	Conversion factor for kilograms per second to pounds per minute
A_h	=	Hole area (square inches)
6.4516 x 10^{-4}	=	Conversion factor for square inches to square meters (HA)
0.5521	=	Conversion factor for square root of feet to square root of meters (h)
0.8	=	Discharge coefficient (0.8)
9.8	=	Gravitational constant (meters per second squared)
D_L	=	Liquid density (pounds per cubic foot)
16.018	=	Conversion factor for pounds per cubic foot to kilograms per cubic meter

For ammonia solution, the factor presented in the text was derived assuming a density of 57.33 lb/ft^3.

Two-Phase Release

For long pipes (L/d_h >> 1, where L is the length of the pipe between the reservoir of chlorine and the atmosphere and d_h is the pipe diameter), there can be flashing in the discharge pipe, and a two-phase mixture emerges to the atmosphere. In this case, the rate of release in lb/min is given by:

$$QR = 9{,}490(A_h)(F)(h_L)/[v_{lg}([T + 460]C_{pl})^{\frac{1}{2}}] \qquad \text{(A-4)}$$

where those symbols not already defined are:

F   a frictional loss factor, which is dimensionless and takes on a value of 1 for L/d_h. 10,
        0.85 for L/d_h . 50, 0.75 for L/d_h . 100, 0.65 for L/d_h . 200, and 0.55 for L/d_h . 400.
h_L the latent heat of vaporization (Btu/lb)
v_{lg} the difference in specific volume between the gas and liquid (lb/ft^3)
T   the reservoir temperature (^{o}F), and
C_{pl} the liquid heat capacity (Btu/lb/^{o}F)

For chlorine, h_L is 124 Btu/lb, v_{lg} = 0.68 lb/ft^3, T = 77 ^{o}F (25 ^{o}C), and C_{pl} = 0.222 Btu/lb/^{o}F.

For sulfur dioxide, v_{lg} = 1.55 ft^3/lb, h_L = 80 Btu/lb, c_{pl} = 0.34 Btu/lb/^{o}F.

Vapor Releases

For a gas release under choked flow conditions (i.e., emerging at the speed of sound from the hole, the maximum flow rate), the following equation can be used to estimate the release rate:

$$m = C_d A_h (\gamma p_0 D_0 [2/(\gamma+1)]^{(\gamma+1)/(\gamma-1)})^{0.5} \tag{A-5}$$

where: m =   Discharge rate (kg/s)
       C_d =   Discharge coefficient
       A_h =   Opening area (m^2)
       γ =   Ratio of specific heats
       p_0 =   Tank pressure (Pascals)
       D_0 =   Density (kg/m^3)

Density (D_0) can be rewritten as a function of pressure and molecular weight, based on the ideal gas law:

$$D_0 = (p_0 \times MW)/R\, T_t \tag{A-6}$$

where: MW =   Molecular weight (kilograms per kilomole)
       R =   Gas constant (8,314 Joules per degree-kilomole)
       T_t =   Tank temperature (K)

The choked flow equation can be rewritten and converted to English units as follows:

$$QR = 132.2 \times A_h \times 6.4516 \times 10^{-4} \times P_a \times 6895 \times 0.8 (\gamma [2/(\gamma+1)]^{(\gamma+1)/(\gamma-1)})^{0.5} \times (MW/8314 \times T_t)^{0.5} \tag{A-7}$$

where: 0.8   =   Discharge coefficient
       132.2   =   Conversion factor for lbs/min to kg/s
       6,895   =   Conversion factor for psi to Pascals (p_0)
       6.4516 x 10^{-4} =   Conversion factor for square inches to square meters (A_h)
       P_a =   Absolute pressure in the reservoir/tank (psia)
       A_h =   Hole area (inches)

To derive the chemical-specific factors for gas releases presented in the text, the temperature (T_t) was assumed to be 298 K, and the following chemical-specific data were substituted into Equation A-2:

Gas	Molecular Weight (MW)	Tank Pressure (P$_a$) (psia)	Ratio of Specific Heats (())
Chlorine	70.91	113	1.32
Sulfur dioxide	64.07	58	1.26

LOG-LOG TABLE EQUATIONS

This section presents formulas for estimating the distance to the endpoint from the rate of release for each of the toxic substances addressed in this document. The formulas are given in the form:

$$D = a\ (QR)^b \qquad (A-9)$$

where: D   =   distance to the endpoint (miles)
         a and b =   chemical-specific factors
         QR   =   release rate (lbs/min)

The formulas for each chemical were developed based on the best straight-line fits to the log-log graphs of release rate versus distance (Figures 4-1 to 4-8). The formulas are easy to use with a scientific calculator and may be used instead of the distance tables or figures. Since the equations are best fits to the curves on Figures 4-1 to 4-8, they may not give exactly the same predictions as appear in the corresponding exhibits.

Chlorine

Worst Case. The guidance on Figure 4-1 is essentially in the form of a straight line on a log-log plot:

$D = 0.2273(QR)^{0.4879}$ for a rural site, and

$D = 0.0878(QR)^{0.5134}$ for an urban site

Alternative. Figure 4-5 is roughly a straight line on a log-log plot:

$D = 0.053(QR)^{0.4647}$ for a rural site, and

$D = 0.026(QR)^{0.4263}$ for an urban site.

Sulfur Dioxide

Worst Case. The guidance on Figure 4-2 is essentially in the form of a straight line on a log-log plot:

$D = 0.165(QR)^{0.5562}$ for a rural site, and

$D = 0.0726(QR)^{0.5419}$ for an urban site.

Alternative. The curves on Figure 4-6 are approximately straight lines on a log-log plot:

$D = 0.047(QR)^{0.4961}$ for a rural site, and

$$D = 0.025(QR)^{0.4407} \text{ for an urban site.}$$

Anhydrous Ammonia

Worst Case. The guidance on Figure 4-3 is essentially in the form of a straight line on a log-log plot:

$$D = 0.0607(QR)^{0.4923} \text{ for a rural site, and}$$

$$D = 0.0443(QR)^{0.4782} \text{ for an urban site.}$$

Alternative. The curves on Figure 4-7 are approximately straight lines on a log-log plot:

$$D = 0.0222(QR)^{0.4780} \text{ at a rural site, and}$$

$$D = 0.0130(QR)^{0.4164} \text{ at an urban site.}$$

Aqueous Ammonia

Worst Case. The guidance on Figure 4-4 is essentially in the form of a straight line on a log-log plot:

$$D = 0.0667(QR)^{0.4617} \text{ for a rural site, and}$$

$$D = 0.0221(QR)^{0.4712} \text{ for an urban site.}$$

Alternative. The curves on Figure 4-8 are roughly straight lines on a log-log plot:

$$D = 0.02(QR)^{0.5174} \text{ for a rural site, and}$$

$$D = 0.0107(QR)^{0.4748} \text{ for an urban site.}$$

APPENDIX 4B
LIMITATIONS OF RESULTS

The guidance in the present document is summarized in the form of various tables and plots giving the predicted distance to the toxic endpoint as a function of the rate of release. There are upper and lower limits on the validity of these tables and plots—the models used are not valid beyond 25 miles, nor at less than 0.06 mile (100 m ~ 300 feet). It should be noted that the guidance presented in this chapter in the form of plots and tables yield predictions that are among many possible. There is, in fact, a wide range of uncertainty, partly due to the still incomplete theoretical understanding of the atmospheric dispersion of large-scale accidental releases of hazardous vapors in the industrial environment, partly due to the need to specify the values of a number of parameters, the values of which may not be well known, and partly because there are relatively few large-scale experimental data sets with which to "tune" the models, especially for the conditions applicable to the worst-case scenario. Therefore, for any given rate of release of a specific material, such as chlorine, there may be a wide variety of predictions by analysts using different models, or using the same model with different input parameters. The potential range of uncertainty is addressed in the Backup Document.

An attempt has been made to develop guidance in the mid-range of possibilities, with the hope that the most extreme conservatisms have been removed, but which is still modestly conservative. As a general (and much simplified) rule, you should not be surprised if, for worst-case scenarios, other analysts and models produce predictions that may be up to a factor of three higher or a factor of three lower than those presented here.

The predictions in the distance tables in the exhibits and all other predictions in this report for regulated toxic chemicals are based upon the methods described in the Backup Document. That method consisted of performing a range of sensitivity studies and then choosing guidance that lies within that range.

There are a number of caveats of which you should be aware.

The results given in the exhibits and figures are not in any absolute sense the "right" or "correct" ones. On the contrary, the Backup Document contains predictions from many sources. The intention there is to establish a range of uncertainties that might be regarded as reasonable by practitioners in the field of atmospheric dispersion modeling, and then to locate a reasonable guidance curve (such as Figure 4-1) within that range of uncertainty. In this way, it is hoped that the following objectives will be achieved:

- g   The facts that the results are uncertain and that there is no uniquely "right" result are not disguised.
- g   Nevertheless, there is a reasonable solution that is easy to use, and users of this guidance do not have to understand its derivation.

As noted above, the further downwind, the more likely it is that you are beyond the range of applicability of any atmospheric dispersion model. That is why, for the 90-ton railcar release of chlorine, the result is stated as "> 25 miles." For such a large release of chlorine, it is unlikely that you will find any model that will predict any less than this distance, and some will predict considerably more. There is no way to avoid the conclusion that the distance to the toxic endpoint for a worst-case release from a 90-ton chlorine railcar is very large, even though the current state of the models does not allow us to say exactly how far "large" is. Note that the discussion in this paragraph applies to railcars that are in the open air.

For the 150-lb and one-ton cylinder case, the results are uncertain to within perhaps a factor of 5-10. The Backup Document shows that, under certain modeling assumptions, the predicted distances could be perhaps a factor of three larger than those stated above or a factor of three smaller. You will also almost certainly be able to find a computer model that can be run to produce even smaller predicted distances. If you opt to do that, you will have to produce justification that the modeling is reasonable. [Note, however, that you are not obliged to use the guidance presented here; you can use whatever model you want provided that you have a solid scientific basis for doing so]. The fact that these large uncertainties exist explains why it is so difficult to develop a single guidance curve that everyone accepts. Many different choices for the guidance could fit comfortably within the range of uncertainties.